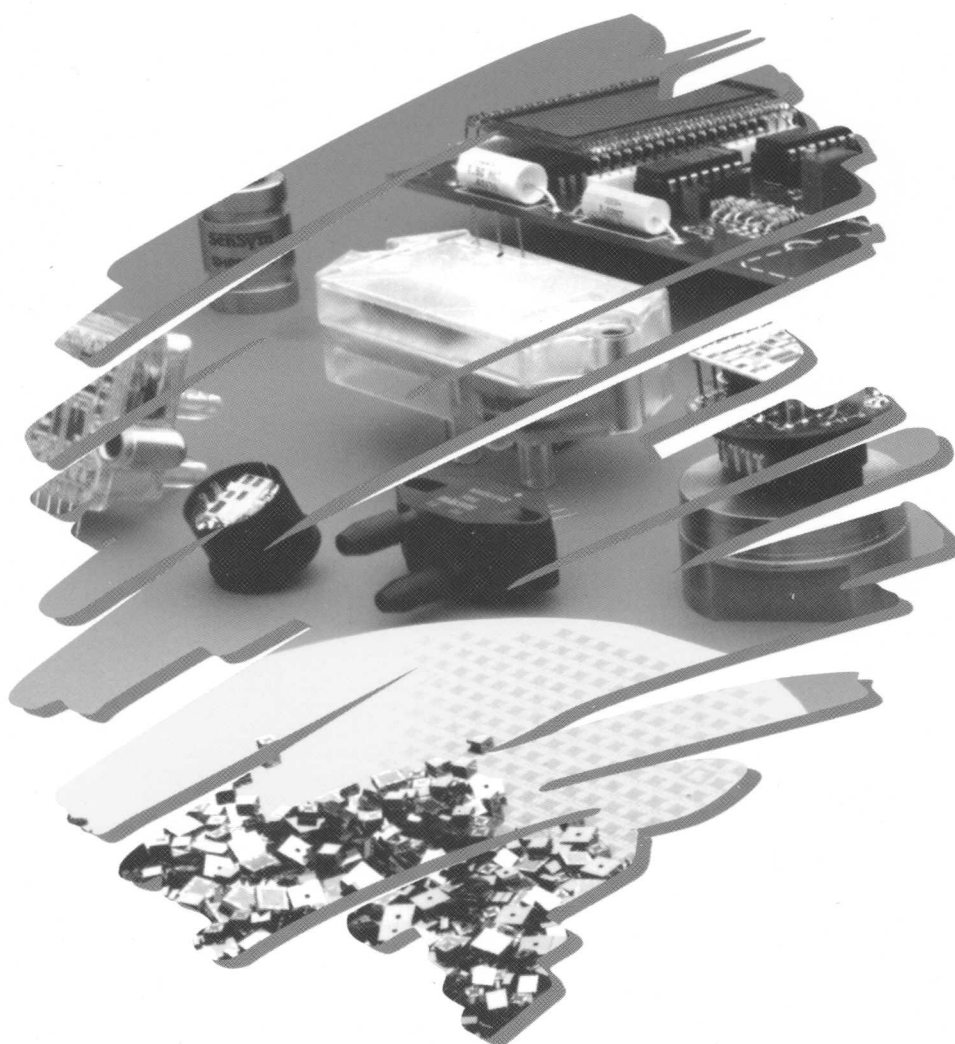


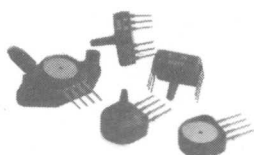


SenSym

**SOLID-STATE PRESSURE SENSORS
HANDBOOK**

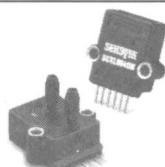
1994

Coming Soon



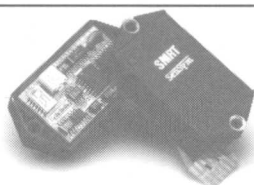
SOC Series

- On-Chip Compensation & Calibration (0°C–70°C)
- 0–1 psi to 0–100 psi
- Available in Small DIP and Other Packages
- Absolute, Gage or Differential Configurations



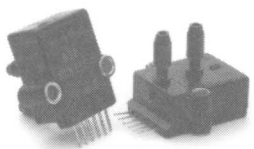
SLP & SCXL Series Low Pressure Sensors

- 0 to 4 inches H₂O and 0 to 10 inches H₂O Full-Scale
- Precision Temperature Compensation (0°C–70°C) or Basic Sensor
- Calibrated Zero and Span



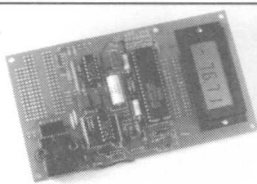
SMRT Series Smart Pressure Instruments

- Serial Digital Output
- Precision Instrument Accuracy: 0.15% Typical. Error (–20°C to +85°C)
- 0–1 to 0–300 psi Pressure Ranges



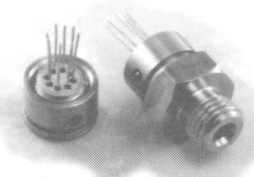
Amplified SCX Series

- Span 0.25V to 4.75V
- 5V Supply
- Very Small Size
- Field Interchangeable



Evaluation Boards

- SCX-EB: Universal Amplifier Board
- SCX-LCD: 3½ Digit LCD Evaluation Board
- SCX-PRL8: A/D Conversion with Parallel Data Output
- SCX-SRL8: A/D Conversion with Serial Data Output
- SCX-EB 4.5 LCD: 4½ Digit LCD Evaluation Board



SSC Stainless Steel Isolated Series

- 0–15 to 0–150 psi
- ½" NPT Male Fitting or Cell Without Fitting
- Small Package
- Accommodates Most Harsh Media

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ERRATA FOR SENSYM'S 1994 HANDBOOK

Page 1-28 SX15 through SX150 Series

Delete the part number SX100AN2 and SX100DN2 in the column headed "Sensor in 1/2 'N' Package".

Change the column headed "Sensor in Nipple Package" to read:

SX15AP1
SX30AP1

—

SX15DP1
SX30DP1

—

Delete the following part numbers in the column headed "Sensor in DIP Package".

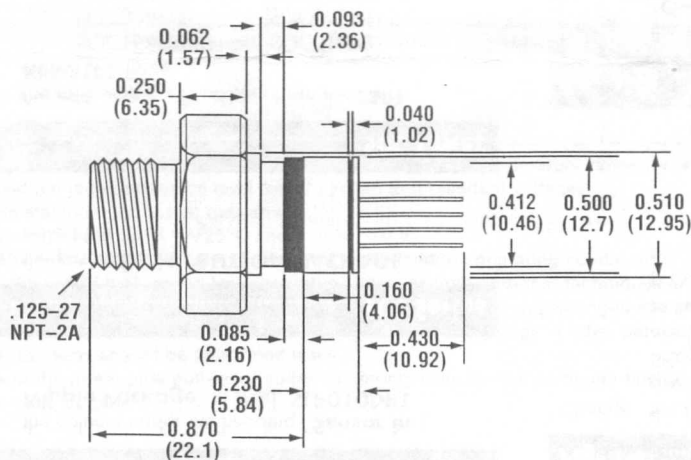
SX15AD3
SX30AD3
SX100AD3
SX150AD3

Page 9-7 Package Outlines

Change the designation for the package at the top of the page from "DP1 Button Package" to "P1 Button Package".

Page 9-5 Package Outlines

Replace the "SSC Package" drawing with the one below:



Sensym

ERRATA FOR SENSYM'S 1994 HANDBOOK

Page A-16 SLP010D

Change the **ELECTRICAL CONNECTIONS** for the **DIP**. The devices in the **DIP** are only available in an "Open Bridge" configuration. The pinouts shown below are for the condition where pressure is applied to the P_2 port or to the back of the sensor die. If the pressure is applied to the P_1 port, or the top of the die, the polarity is reversed.

- | | |
|---------------|---------------|
| 1) $+V_{OUT}$ | 6) $+V_S$ |
| 2) GROUND | 5) No Connect |
| 3) $-V_{OUT}$ | 4) $-V_S$ |

Page A-18 SLP010D

Change the column under the heading "**Sensor in Nipple Package**" to read: **SLP010DP1**

Page A-19 SOC Series

Change the pinout for the "**BUTTON PACKAGE**" to reflect Pin 3) as $+V_S$

Page A-21 SOC Series

Delete the following part numbers from the **PART NUMBERS** Table:

- | | |
|-------------|-------------|
| SOC15AD3 | SOC01DP2 |
| SOC30AD3 | SOC05DP2 |
| SOC100AD3 | SOC15DP2 |
| SOC15AP2 | SOC30DP2 |
| SOC30AP2 | SOC100AP1,2 |
| SOC100DP1,2 | |

Page 1-3 SCC Series

Change the **ELECTRICAL CONNECTIONS** for the **DIP**. The devices in the **DIP** are only available in an "Open Bridge" configuration. The pinouts shown below are for the condition where pressure is applied to the P_2 port, or to the back of the die. If the pressure is applied to the P_1 port or the top of the die, the polarity is reversed.

- | | |
|---------------|---------------|
| 1) $+V_{OUT}$ | 6) $+V_S$ |
| 2) GROUND | 5) No Connect |
| 3) $-V_{OUT}$ | 4) $-V_S$ |

Page 1-8 SCC Series

Add part number SCC100GSO in the column headed "**Sensor in TO Package (Open Bridge)**".

Delete the entire column headed "**Sensor in TO-5 Package**".

Delete the following part numbers from the column headed "**Sensor in DIP Package**".

- SCC05AD3
SCC15AD3
SCC30AD3
SCC100AD3

Page 1-9 SX01, SX05

Change the **ELECTRICAL CONNECTIONS** for the **DIP**. The devices in the **DIP** are only available in an "Open Bridge" configuration. The pinouts shown below are for the condition where pressure is applied to the P_2 port, or to the back of the die. If the pressure is applied to the P_1 port or the top of the die, the polarity is reversed.

- | | |
|---------------|---------------|
| 1) $+V_{OUT}$ | 6) $+V_S$ |
| 2) GROUND | 5) No Connect |
| 3) $-V_{OUT}$ | 4) $-V_S$ |

Page 1-18 SX01, SX05

Delete the "0 to 5 psia" line from the bottom of the "**Order Part Number**" table.

Page 1-19 SX15 through SX150 Series

Change the **ELECTRICAL CONNECTIONS** for the **DIP**. The devices in the **DIP** are only available in an "Open Bridge" configuration. The pinouts shown below are for the condition where pressure is applied to the P_2 port, or to the back of the die. If the pressure is applied to the P_1 port or the top of the die, the polarity is reversed.

- | | |
|---------------|---------------|
| 1) $+V_{OUT}$ | 6) $+V_S$ |
| 2) GROUND | 5) No Connect |
| 3) $-V_{OUT}$ | 4) $-V_S$ |

Sensym

CONTINUED ON BACKSIDE

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Although we provide assistance on SenSym products both personally and through our literature, it is still the total responsibility of the customers to determine the suitability of any product in their application.

1993/1994 Updates

The following are product line changes from the 1992 edition of the SenSym Pressure Sensor Handbook:

Additions:

- Amplified SCX Series — Amplified versions of SenSym's proven SCX sensor family
- DIP Package — A DIP package for any SenSym die family
- SCXL010DN — 0 to 10 inch H₂O temperature compensated
- SCX-EB 4.5 LCD — 4½ Digit board with 0–5V analog output
- SLP010D Series — 0 to 10 inch H₂O Basic Sensor
- SOC Series — On-Chip compensated
- SSC Series — Stainless steel isolated, low & medium pressure

Sample Policy

SenSym is very liberal in providing samples for evaluation. Please contact our factory or your local SenSym representative with your request.

Preface

Here is your new 1993/1994 catalog and handbook of integrated circuit sensors from SenSym. It contains:

- General information about solid state pressure sensors
- Up-to-date product information and specifications
- Descriptions of typical sensor applications.

Integrated circuit sensors are being used in a wide variety of applications. Furthermore, the scope of solid state sensor applications is growing rapidly with the availability of low-cost microprocessors and microcomputers for automation and control. We hope that this book provides the necessary insight into understanding and using SenSym's sensors.

For information on devices introduced after the date of this printing, or for more information on listed devices or applications, please contact your SenSym representative or SenSym directly.

This edition supercedes all previous catalogs, specifications, and application notes.

Package Styles & Physical Dimensions

See Section 9 for all Package Styles and Dimensions and Section 10 for Accessories.

INTRODUCTION

This section of the handbook provides an overview of the technology (in layman's terms) and a brief description of the different types of sensor products available from SenSym. It is meant as a brief introduction to those of you unfamiliar with SenSym's technology and/or products.

Piezoresistive pressure sensors (strain gage sensors) are fabricated using silicon processing techniques common in the semiconductor industry. For this reason they have taken on some of the semiconductor terminology.

Piezoresistive sensors are often referred to as IC sensors (integrated circuit), solid state sensors, monolithic sensors (formed from single crystal silicon) or just silicon sensors. All SenSym sensors are piezoresistive silicon sensors. They are processed in wafer form, where each 4" wafer will contain a few hundred to a few thousand sensor die depending on the size of the sensor die (a typical sensor chip measures 80 x 80 mils or 2mm x 2mm). A standard run of 24 wafers can be processed at one time, producing, on average 24,000 sensor die per run.

Sensor Fabrication and Basic Characteristics

For most SenSym sensors, four strain sensitive resistors are ion implanted into silicon wafers using standard semiconductor photolithography techniques. These resistors are connected in a wheatstone bridge configuration whereby two resistors increase with positive pressure while the other two decrease in resistance (see Figure 1).

In simple mathematical terms the sensor can be modeled as follows:

When pressure is applied to the device (see Figure 1) the resistors in the arms of the bridge change by an amount, Δ . The alignment of the

resistor on the silicon determines if the resistor will increase or decrease with applied pressure.

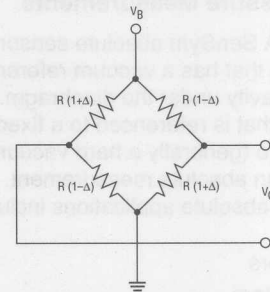


Figure 1.

The resulting differential output voltage V_O , is easily shown to be $V_O = V_B \Delta$. Since the change in resistance, is directly proportional to pressure, V_O can be written as:

$$V_O = (S \times P \times V_B) \pm V_{OS}$$

Where: V_O is the output voltage in mV.

S is the sensitivity in mV/V per psi

P is the pressure in psi

V_B is the bridge voltage in volts.

V_{OS} is the offset error (the differential output voltage when the applied pressure is zero).

After processing of the top surface of the silicon wafer is completed to form the resistors and interconnections, a diaphragm is created by chemically etching the silicon from the back side. The diaphragm thickness determines the pressure range (sensitivity) of the sensor. This relationship is not a linear function; for example, doubling the thickness of the diaphragm decreases the sensitivity by a factor of four. Typical diaphragm thicknesses are 5 to 200 microns, depending on the pressure range (pretty thin stuff). As pressure is applied to the sensor the resistors are strained, causing an imbalance in the wheatstone bridge proportional to the applied pressure. The differential output of the raw sensor is, however, not precise in terms of calibration and temperature effects.

For example, on a single wafer the range of sensitivity from die-to-die can be as high as 2:1. It is partially because of this that SenSym offers a variety of levels of signal conditioned sensors from the basic "raw" state up through fully calibrated and compensated transmitters.

Types of Pressure Measurements

ABSOLUTE - A SenSym absolute sensor refers to a chip that has a vacuum reference sealed in the cavity under the diaphragm. Any measurement that is referenced to a fixed reference pressure (generally a hard vacuum) is referred to as an absolute measurement. The more common absolute applications include:

- Altimeters
- Barometers
- Vacuum measurements

In some applications an absolute sensor may be used for convenience. Since the sensor has the reference pressure sealed inside the chip it only requires one pressure input. In applications such as depth measurements the sensor can be submerged in liquid without the need of a vent (reference pressure) tube to the surface.

GAGE - A SenSym gage sensor refers to a chip that has the reference cavity vented to atmosphere. Any measurement that is referenced to barometric pressure is called a gage measurement. The sensor will measure positive and negative pressures (pressures greater than and less than barometric pressure). Gage sensors are useful in equipment that may be taken from one altitude to another. The sensor automatically compensates for any change in barometric pressure (barometric pressure is the reference pressure). Hence, airplanes and automobiles can measure air speed and engine vacuum at sea level and at 10,000 feet with the same accuracy.

Typical gage pressure applications are:

- Blood pressure
- Engine vacuum
- Tire pressure

DIFFERENTIAL - A measurement where one pressure is measured relative to a second pressure will use a differential sensor. Since gage measurements are actually a special type of differential measurement the same basic sensor is used for both sensors. A second pressure port is added for the differential sensor.

Typical differential pressure applications are:

- Air flow
- Filter status

SENSOR SELECTION

This handbook is arranged in sections which specify basic sensors, compensated sensors and fully signal conditioned devices. The basic differences in the levels of signal conditioning are explained herein.

Basic Sensor Element

The basic sensor element is the simplest form of sensor available from SenSym. These products feature:

- Packaged sensor (plastic, ceramic, T0-5 can, or stainless steel isolated)
- Pressure tested
- No external temperature compensation
- No calibration
- Lowest cost

Basic sensor product families from SenSym include the SCC, SPX, SX, SSC series. The basic differences between these families are:

- **SCC Series** – Offers limited span temperature compensation when excited with a constant current source. Small sensor chip offers lowest cost.

- SLP010 – New 10 inch H₂O sensor in DIP or Button package, shear sensor element.
- SPX Series – Offers a low impedance shear sensor element.
- SSC Series – Low to medium pressure, small stainless steel isolated sensor.
- SX Series – General purpose, ultra stable, high impedance sensor. Larger chip allows higher signals at low pressure.

Temperature Compensated and Calibrated Sensor

These sensors are the most user friendly and require a minimum value-added by the user. The output in millivolts is extremely flexible and easily adapted to microprocessor based systems. The basic features are as follows:

- Basic sensor + laser trimmed compensation
- Temperature compensated
- Calibrated (offset and span adjusted)
- Moderate Cost

Sensors in this family include the SCX, SOC and SSX series. Features of each are:

- SCX Series – Plastic housing. High performance/low cost.
- SCXL – Very low pressure temperature compensated in plastic housing.
- SOC Series – On-Chip compensated sensors in small plastic packages.
- SSX Series – Stainless steel isolated package for rugged applications.

High Level Output Devices

The high level output sensors take the basic approach of the TC sensors described previously and then add an amplifier to achieve a voltage output typically in the range of 1-6

V_{DC}. Features are:

- Temperature compensated
- Calibrated (offset and span adjusted)
- Amplified Voltage or Current (4-20 mA) Outputs

Sensors in this class of devices include the new Amplified SCX, 142SC, ST2000, and the SMRT digital output products. Features of each family are:

- 140SC Series – 1-6 V_{DC} high level output in a plastic package.
- Amplified SCX Series – 0.25 to 4.75V output, 5V supply.
- SMRT Series – High precision digital output in a standard plastic package.
- ST2000 Series – 1-6 V_{DC} and 4-20 mA outputs in a media isolated stainless steel package.

As a general rule, the basic sensors and temperature compensated sensors can be used to measure positive as well as negative gage pressures and will measure pressures higher than the calibration pressure (until the diaphragm ruptures). The signal conditioned devices are limited to the specific pressure range and voltage swing for which they are calibrated.

CONCLUSION

This introduction was designed to give a brief overview of the products and technology available from SenSym. The individual product datasheets and application notes will give specific details about each of the products. Please call us if you have any questions or concerns. We have on-line application engineers waiting to serve you. We wish you luck with your sensor application and hope you find our Handbook useful.

PRESSURE SENSORS

Selection and Application

(Mechanical Engineering Series/72)

DUANE TANDESKE

SenSym, Inc.

November, 1990

312 pages, illustrated

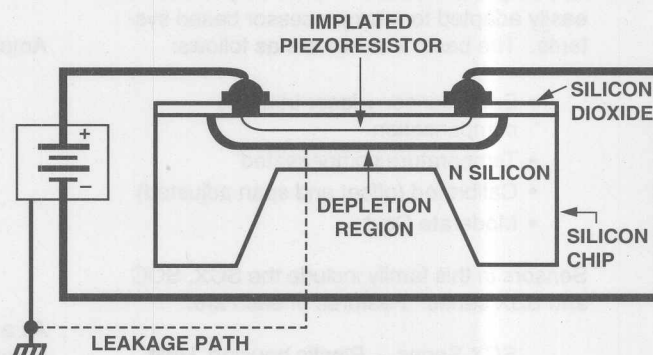
This practical handbook provides the knowledge needed to specify and apply **the best** piezoresistive pressure sensors to interface with today's microprocessors and computers.

Get vital information fast while minimizing trial and error!

Eliminating unnecessary details on semiconductor physics or sensor design methods, **Pressure Sensors...**

- clarifies the three kinds of pressure measurement, making it easier to determine the most appropriate sensor for each application
- explains silicon sensor design fundamentals, showing how to employ the sensors properly
- reviews basic—but often overlooked—aspects of sensor usage
- describes recent progress in micro-machining and pressure sensors

Pressure Sensors is an indispensable timesaving tool for mechanical and circuit design engineers involved in sensor applications and instrumentation, and upper-level undergraduate students of electrical engineering and physics.



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Pressure Fundamentals
Pressure Terminology
Common Transduction Methods
Piezoresistive Sensors
Sensor Specifications
Signal Conditioning
Sensor Selection
Auto-Zero and Auto-Reference Techniques
Computer Interface Techniques
Applications
Future Trends
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ISBN: 0-8257-8365-4

Available From:

**Marcel
Dekker,
Inc.**

To Order Call:
1-800-228-1160

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SenSym Custom Products

In addition to the standard product line, SenSym manufactures a variety of custom products. These custom products can feature IC pressure sensor elements which are signal-conditioned and packaged to meet a variety of applications beyond those served by the standard product line. In regard to using custom products, SenSym will design and develop products to meet a specific application's requirements.

Typical Custom Products

SenSym's custom products range from relatively simple modifications to our standard part, such as different scaling of an output voltage, to a variety of products in different pressure ranges, mechanical housings and electrical specifications. Typical custom products consist of various combinations of the following features:

- Output Scaling
- Tighter Tolerances on Offset and Span
- Special Parametric Selections
- Special Output Features
- Special Pressure Ranges
- Special Mechanical Housings

Custom Product Policies

All custom products require interface with the factory. Development charges, product prices, and lead times can vary significantly and each custom product is evaluated on an individual basis.

All custom products are assigned special part numbers, typically SZ#XXXX.

Typically, the following policies will apply for custom products:

- Minimum Order Quantity of 100 Pieces (Non-cancellable)
- Factory Interface Required for Initial Order
- Pricing and Lead Time Established on an Individual Basis

For further information on custom products, please consult your local SenSym representative or the factory directly.



Warranty

SenSym, Inc. warrants that its products shall be free from defects in workmanship and materials, and shall conform to SenSym's published specifications, or other specifications accepted by SenSym in writing for a period of three (3) years from the date of SenSym's shipment.

Limitation of Warranty Liability:

This warranty does not apply to any products which have been subject to misuse, neglect, accident, or modification. SenSym's sole obligation under its warranty shall be to replace the product or issue credit. SenSym's warranty and remedies are exclusive and are made expressly in lieu of all other warranties expressed or implied, either in fact or by operation of law, statutory or otherwise, including warranties of merchantability and fitness for use. SenSym shall not be liable for damages due to delays in deliveries or use and shall in no event be liable for incidental or consequential damages of any kind, whether arising from contract, tort, or negligence, including but not limited to, loss of profits, loss of customers, loss of goodwill, overhead, or other like damages.

Limitation of Application Liability:

SenSym assumes the buyer to be expert in his intended application of SenSym's products. SenSym claims no special expertise in the application of its products into the buyer's equipment. SenSym accepts no responsibility for the buyers selection and use of SenSym's products. Buyer's interpretation and implementation of application suggestions and recommendation by SenSym, general or specific, transmitted verbally or in writing, published or unpublished, is strictly at the buyer's own risk.

SenSym Failure Analysis Policy:

1. SenSym will provide a failure analysis at no charge for any SenSym parts for up to three (3) years after product shipment.
2. SenSym will continue to provide failure analysis at a nominal charge for SenSym products for up to five (5) years after product shipment.
3. SenSym reserves the right to no longer provide failure analysis services after five (5) years.

Sample Policy:

SenSym is very liberal in providing samples for evaluation. Please contact our factory or your local SenSym representative with your request.

Note:

All Terms & Conditions published in SenSym's "Short Form Catalog & OEM Price List" are applicable to all business transactions. Please refer to those Terms & Conditions.

TRANSDUCER SELECTION GUIDE

MONOLITHIC DEVICES

Reference Temperature = 25°C, $V_E = 5.0V_{DC}$ for SLP, SSC and SX, $3.0V_{DC}$ for SPX; Operating Temperature Range = 0° to 50°C for SLP, -40°C to 85°C for SSC and SX, -40°C to +125°C for SPX; Reference Pressure = Minimum Operating Pressure.

Device Type	Operating Pressure Range	Maximum Over Pressure	Offset Calibration mV	Sensitivity mV/psi mV	Linearity (Note 1) $\pm$ % FS (Typical)	Repeatability and Hysteresis $\pm$ % FS (Typical)	Offset Shift w/Temperature (0°C to 50°C) $\pm$ mV (Typical)	Sensitivity Shift w/Temperature (0°C to 50°C) $\pm$ % FS (Typical)	Full-Scale Output Calibration mV (Typical)
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Absolute Pressure Devices

SPX100A(N)	0 to 15 psia	30 psia	0 to 35	4.0	0.1	0.5	0.75	1.2	60
SPX200A(N)	0 to 30 psia	60 psia	0 to 35	2.0	0.1	0.5	0.75	1.2	60

SSC15A	0 to 15 psia	30 psia	-35 to 0	18	0.2	0.5	1.2	5	110
SSC30A	0 to 30 psia	60 psia	-35 to 0	9	0.2	0.5	1.2	5	110
SSC100A	0 to 100 psia	200 psia	-35 to 0	3.6	0.1	0.5	1.2	5	150
SSC150A	0 to 150 psia	200 psia	-35 to 0	1.8	0.1	0.5	1.2	5	110

SX15A(N)	0 to 15 psia	30 psia	-35 to 0	18.0	0.2	0.5	1.2	5	110
SX30A(N)	0 to 30 psia	60 psia	-35 to 0	9.0	0.2	0.5	1.2	5	110
SX100A(N)	0 to 100 psia	150 psia	-35 to 0	3.6	0.1	0.5	1.2	5	150
SX150A(N)	0 to 150 psia	200 psia	-35 to 0	1.8	0.1	0.5	1.2	5	110

Differential Pressure Devices

SLP010D	0-10 in. H ₂ O	5 psid	± 50	1mV/in. H ₂ O	0.5	0.5	$\pm 4\mu V/V/^\circ C$	0.1	50
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SPX50D(N)	0 to 7 psid	15 psid	0 to 35	8.6	0.1	0.5	0.75	1.2	60
SPX100D(N)	0 to 15 psid	30 psid	0 to 35	4.0	0.1	0.5	0.75	1.2	60
SPX200D(N)	0 to 30 psid	60 psid	0 to 35	2.0	0.1	0.5	0.75	1.2	60

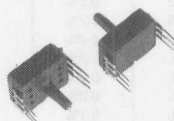
SX01D(N)	0 to 1 psid	20 psi	-35 to 0	48	0.2	0.5	1.2	5	20
SX05D(N)	0 to 5 psid	20 psi	-35 to 0	36	0.2	0.5	1.2	5	75
SX15D(N)	0 to 15 psid	30 psid	-35 to 0	18	0.2	0.5	1.2	5	110
SX30D(N)	0 to 30 psid	60 psid	-35 to 0	9	0.2	0.5	1.2	5	110
SX100D(N)	0 to 100 psid	150 psid	-35 to 0	3.6	0.1	0.5	1.2	5	150
SX150D(N)	0 to 150 psid	200 psid	-35 to 0	1.8	0.1	0.5	1.2	5	110

Gage Pressure Devices

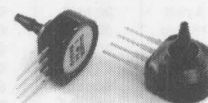
SSC15G	0 to 15 psig	30 psig	-35 to 0	18	0.2	0.5	1.2	5	110
SSC30G	0 to 30 psig	60 psig	-35 to 0	9	0.2	0.5	1.2	5	110
SSC100G	0 to 100 psig	200 psig	-35 to 0	3.6	0.1	0.5	1.2	5	150
SSC150G	0 to 150 psig	200 psig	-35 to 0	1.8	0.1	0.5	1.2	5	110



1/2 "N"



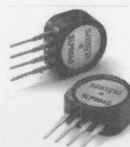
DIP



Button w/Nipple Attached



SPX "N"



Button



SX "N"

TRANSDUCER SELECTION GUIDE

TEMPERATURE COMPENSATED MONOLITHIC DEVICES

Reference Supply Voltage = 10V for LX, 12V for SCX, 5V for SOC; Reference Temperature = 25°C.

Device Type	Operating Pressure Range	Maximum Over Pressure	Offset Calibration mV	Sensitivity mV/psi mV	Linearity (Note 1) ± % FS (Typical)	Repeatability and Hysteresis ± % FS (Typical)	Offset Shift w/Temperature (0°C to 50°C) ± mV (Typical)	Sensitivity Shift w/Temperature (0°C to 50°C) ± % FS (Typical)	Full-Scale Output Calibration mV (Typical)
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Absolute Pressure Devices

LX06015A	0 to 15 psia	60 psia	0 ± 2.0	- 6.67	1.0	0.1	2.0	1.5	- 100
LX06030A	0 to 30 psia	60 psia	0 ± 2.0	- 2.63	0.5	0.5	2.0	1.5	- 79
LX06100A	0 to 100 psia	200 psia	0 ± 2.0	- 1.4	0.5	0.1	2.0	1.5	- 140

SCX15AN	0 - 15 psia	30 psia	0 ± 0.5	6.0	0.1%	—	0.1	0.2	90
SCX15ANC	0 - 15 psia	30 psia	0 ± 10	6.0	0.2%	—	0.2	0.4	90
SCX30AN	0 - 30 psia	60 psia	0 ± 50	3.0	0.1%	—	0.1	0.2	90
SCX30ANC	0 - 30 psia	60 psia	0 ± 10	3.0	0.2%	—	0.2	0.4	90
SCX100AN	0 - 100 psia	150 psia	0 ± 50	1.0	0.1%	—	0.1	0.2	100
SCX100ANC	0 - 100 psia	150 psia	0 ± 10	1.0	0.2%	—	0.2	0.4	100

SOC15A	0 - 15 psia	30 psia	0 ± 0.5	3.33	0.1	0.2	0.10	0.2	50
SOC30A	0 - 30 psia	60 psia	0 ± 0.5	1.67	0.1	0.2	0.10	0.2	50
SOC100A	0 - 100 psia	150 psia	0 ± 0.5	0.5	0.1	0.2	0.10	0.2	50

Gage Pressure Devices

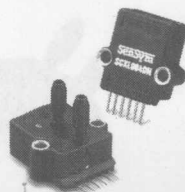
LX06001G	0 to ± 1 psig	20 psig	0 ± 2.0	27.7	1.5	0.1	2.0	1.5	28
LX06002G	0 to ± 2 psig	20 psig	0 ± 2.0	20.0	1.5	0.1	2.0	1.5	40
LX06005G	0 to ± 5 psig	20 psig	0 ± 1.0	10.0	1.5	0.1	2.0	1.5	50
LX06015G	0 to ± 15 psig	40 psig	0 ± 1.0	6.67	1.0	0.1	2.0	1.5	100
LX06030G	0 to 30 psig	60 psig	0 ± 1.0	2.63	0.5	0.1	2.0	1.5	79
LX06100G	0 to 100 psig	200 psig	0 ± 1.0	1.4	0.5	0.1	2.0	1.5	140

Differential Pressure Devices

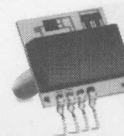
LX06001D	± 1 psid	20 psid	0 ± 2.0	27.7	1.5	0.1	2.0	1.5	28
LX06002D	± 2 psid	20 psid	0 ± 2.0	20.0	1.5	0.1	2.0	1.5	40
LX06005D	± 5 psid	20 psid	0 ± 1.0	10.0	1.5	0.1	2.0	1.5	50.0
LX06015D	± 15 psid	40 psid	0 ± 1.0	6.67	1.0	0.1	2.0	1.5	100
LX06030D	± 30 psid	60 psid	0 ± 1.0	2.63	0.5	0.1	2.0	1.5	79

SCXL004DN	0 - 4" H ₂ O	5 psi	0 ± 1.5	10mV/in. H ₂ O	0.5	0.5	0.5	0.5	40
SCXL010DN	0 - 10" H ₂ O	5 psi	0 ± 1.0	5mV/in. H ₂ O	0.5	0.2	0.5	0.5	50

SCX01DN	0 - 1 psid	20 psid	0 ± 0.3	18.0	0.1%	—	0.1	0.2	18
SCX01DNC	0 - 1 psid	20 psid	0 ± 1.0	18.0	0.2%	—	0.2	0.4	18
SCX05DN	0 - 5 psid	20 psid	0 ± 0.3	12.0	0.1%	—	0.1	0.2	60
SCX05DNC	0 - 5 psid	20 psid	0 ± 1.0	12.0	0.2%	—	0.2	0.4	60
SCX15DN	0 - 15 psid	30 psid	0 ± 0.3	6.0	0.1%	—	0.1	0.2	90
SCX15DNC	0 - 15 psid	30 psid	0 ± 1.0	6.0	0.2%	—	0.2	0.4	90
SCX30DN	0 - 30 psid	60 psid	0 ± 0.3	3.0	0.1%	—	0.1	0.2	90
SCX30DNC	0 - 30 psid	60 psid	0 ± 1.0	3.0	0.2%	—	0.2	0.4	90
SCX100DN	0 - 100 psid	150 psid	0 ± 0.3	1.0	0.1%	—	0.1	0.2	100
SCX100DNC	0 - 100 psid	150 psid	0 ± 1.0	1.0	0.2%	—	0.2	0.4	100
SCX150DN	0 - 150 psid	200 psid	0 ± 0.3	0.6	0.1%	—	0.1	0.2	90
SCX150DNC	0 - 150 psid	200 psid	0 ± 1.0	0.6	0.2%	—	0.2	0.4	90



SCX



LX06XXX

TRANSDUCER SELECTION GUIDE

TEMPERATURE COMPENSATED MONOLITHIC DEVICES (Con't)

Reference Supply Voltage = 5V for SOC, 12V for SSX; Reference Temperature = 25°C.

Device Type	Operating Pressure Range	Maximum Over Pressure	Offset Calibration mV	Sensitivity mV/psi mV	Linearity (Note 1) $\pm$ % FS (Typical)	Repeatability and Hysteresis $\pm$ % FS (Typical)	Offset Shift w/Temperature (0°C to 50°C) $\pm$ mV (Typical)	Sensitivity Shift w/Temperature (0°C to 50°C) $\pm$ % FS (Typical)	Full-Scale Output Calibration mV (Typical)
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Differential Pressure Devices (Con't.)

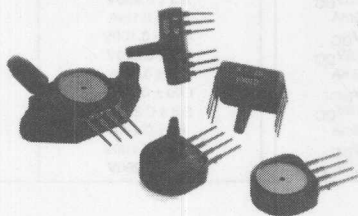
SOC01D	0 – 1 psid	20 psid	0 $\pm$ 0.5	25	0.1	0.2	0.1	0.2	50
SOC05D	0 – 5 psid	20 psid	0 $\pm$ 0.5	10	0.1	0.2	0.1	0.2	50
SOC15D	0 – 15 psid	30 psid	0 $\pm$ 0.5	3.33	0.1	0.2	0.1	0.2	50
SOC30D	0 – 30 psid	60 psid	0 $\pm$ 0.5	1.67	0.1	0.2	0.1	0.2	50
SOC100D	0 – 100 psid	150 psid	0 $\pm$ 0.5	0.5	0.1	0.2	0.1	0.2	50

SSX “G” SERIES

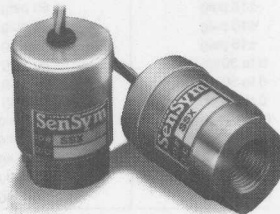
Supply Voltage = 12V_{DC}; Temperature = 25°C.

Gage Pressure Devices

SSX15G	0 – 15 psig	30 psig	0 $\pm$ 0.5	6.0	0.1%	—	0.2	0.5	90
SSX30G	0 – 30 psig	60 psig	0 $\pm$ 0.5	3.0	0.1%	—	0.2	0.5	90
SSX100G	0 – 100 psig	200 psig	0 $\pm$ 0.5	1.0	0.1%	—	0.2	0.5	100
SSX300G	0 – 300 psig	450 psig	0 $\pm$ 0.5	0.2	0.1%	—	0.2	0.5	60
SSX500G	0 – 500 psig	600 psig	0 $\pm$ 0.5	0.2	0.1%	—	0.2	0.5	100



SOC



SSX “G”

TRANSDUCER SELECTION GUIDE

SIGNAL CONDITIONED DEVICES

Device Type	Operating Pressure Range	Maximum Over Pressure	Output Voltage	Offset Calibration	Temperature Effects 0 – 70%
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Absolute Pressure Devices

142SC15A	0 to 15 psia	45 psia	1 to 6V _{DC}	1.00 ± 0.05	1.0%
142SC30A	0 to 30 psia	60 psia	1 to 6V _{DC}	1.00 ± 0.05	1.0%
ASCX15AN1	0 to 15 psia	45 psia	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX30AN1	0 to 30 psia	60 psia	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX100AN1	0 to 100 psia	150 psia	0.25 to 4.75V	0 ± 0.25V	0.5%

Differential Pressure Devices

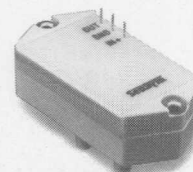
142SC01D	0 to 1 psid	20 psig	1 to 6V _{DC}	1.00 ± 0.05	1.0%
142SC05D	0 to 5 psid	20 psig	1 to 6V _{DC}	1.00 ± 0.05	1.0%
142SC15D	0 to 15 psid	45 psig	1 to 6V _{DC}	1.00 ± 0.05	1.0%
142SC30D	0 to 30 psid	60 psig	1 to 6V _{DC}	1.00 ± 0.05	1.0%
142SC100D	0 to 100 psid	150 psig	1 to 6V _{DC}	1.00 ± 0.05	1.0%
ASCX01DN1	0 to 1 psid	20 psig	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX05DN1	0 to 5 psid	20 psig	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX15DN1	0 to 15 psid	30 psig	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX30DN1	0 to 30 psid	60 psig	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX100DN1	0 to 100 psid	150 psig	0.25 to 4.75V	0 ± 0.25V	0.5%
ASCX150DN1	0 to 150 psid	150 psig	0.25 to 4.75V	0 ± 0.25V	0.5%

Stainless Steel Transducers – Gage Pressure Devices

ST2015G1	0 to 15 psig	60 psig	1 to 6V _{DC}	1.00 ± 0.100V	1.5%
ST2015G2	0 to 15 psig	60 psig	2.5 to 12.5V _{DC}	2.5 ± 0.200V	1.5%
ST2015G4	0 to 15 psig	60 psig	4 to 20mA	4.0 ± 0.1mA	1.5%
ST2P15G1	±15 psig	60 psig	1 to 6V _{DC}	1.00 ± 0.100V	1.5%
ST2P15G2	±15 psig	60 psig	2.5 to 12.5V _{DC}	2.5 ± 0.200V	1.5%
ST2P15G4	±15 psig	60 psig	4 to 20mA	4.0 ± 0.1mA	1.5%
ST2030G1	0 to 30 psig	60 psig	1 to 6V _{DC}	1.00 ± 0.100V	1.5%
ST2030G2	0 to 30 psig	60 psig	2.5 to 12.5V _{DC}	2.5 ± 0.200V	1.5%
ST2030G4	0 to 30 psig	60 psig	4 to 20mA	4.0 ± 0.1mA	1.5%
ST2100G1	0 to 100 psig	200 psig	1 to 6V _{DC}	1.00 ± 0.100V	1.5%
ST2100G2	0 to 100 psig	200 psig	2.5 to 12.5V _{DC}	2.5 ± 0.200V	1.5%
ST2100G4	0 to 100 psig	200 psig	4 to 20mA	4.0 ± 0.1mA	1.5%
ST2300G1	0 to 300 psig	450 psig	1 to 6V _{DC}	1.00 ± 0.100V	1.5%
ST2300G2	0 to 300 psig	450 psig	2.5 to 12.5V _{DC}	2.5 ± 0.200V	1.5%



ST2000



142SC

INSTRUMENT SELECTION GUIDE

PRECISION DIGITAL MANOMETERS

Model Number	Pressure Range		Resolution		Units (gage)	Accuracy
	Low	High	Low	High		
PDM 10B	NONE	0 – 10.00	—	0.01	bar	± 0.5% of Reading or ± 1 count
PDM 100P	NONE	0 – 100.00	—	0.1	PSI	± 0.5% of Reading or ± 1 count
PDM 200B	0 – 199.9	0 – 1999	0.1	1.0	millibar	± 0.5% of Reading or ± 1 count
PDM 2B	0 – 1.999	0 – 10.00	0.001	0.01	bar	± 0.5% of Reading or ± 1 count
PDM 200M	0 – 199.9	0 – 1000	0.1	1.0	mmHg	± 0.5% of Reading or ± 1 count
PDM 20P	0 – 19.99	0 – 100.0	0.01	0.1	PSI	± 0.5% of Reading or ± 1 count
PDM 200BD	0 – 199.9	0 – 1999	0.1	1.0	millibar (differential)	± 0.5% of Reading or ± 1 count
PDM 20ID	0 – 19.99	0 – 199.9	0.01	0.1	IN WC (differential)	± 0.5% of Reading or ± 1 count

PRECISION INSTRUMENT GRADE TRANSDUCERS

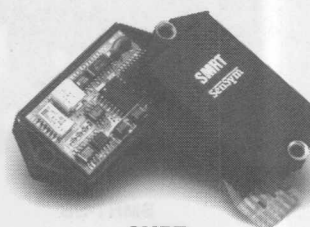
DIGITALLY COMPENSATED, DIGITAL OUTPUT

Maximum Total Error Over –20°C to +85°C is 0.5%

SenSym Part #	Operating Pressure Range	Burst Pressure
SMRT01D1	0 – 1 psid	10 psig
SMRT01D2	± 1 psid	10 psig
SMRT05D1	0 – 5 psid	20 psig
SMRT05D2	± 5 psid	20 psig
SMRT15D1	0 – 15 psid	45 psig
SMRT15D2	± 15 psid	45 psig
SMRT15A1	0 – 15 psia	45 psia
SMRTBAR01	20 – 32 In Hg (Abs)	75 In Hg (Abs)
SMRT30D1	0 – 30 psid	60 psig
SMRT30A1	0 – 30 psia	60 psia
SMRT100D1	0 – 100 psid	150 psig
SMRT100A1	0 – 100 psia	150 psia



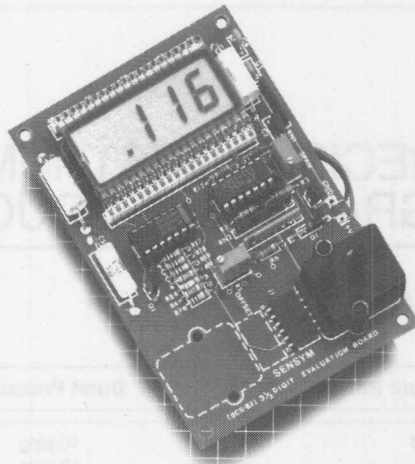
PDM



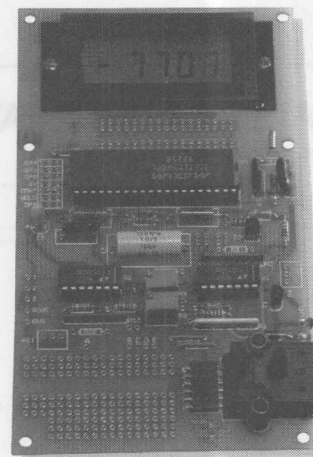
SMRT

EVALUATION BOARDS SELECTION GUIDE

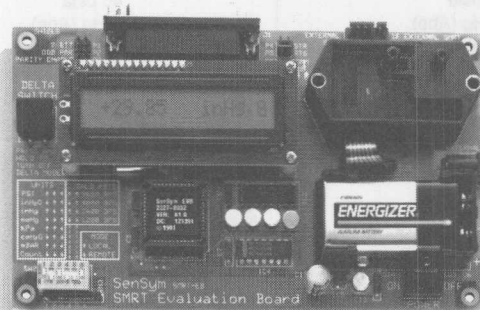
Board Series	Description
SCX-EB	Analog Output (0 – 5V, 1 – 6V)
SCX-PRL8	8-bit Parallel Output
SCX-SRL8	8-bit Serial Output
SCX-LCD	3½ Digit Display
SCX-EB 4.5 LCD	4.5 Digit Display & Analog Output (0 – 5V)
SMRT-EB	LCD Evaluation Board for the SMRT Series



SCX-LCD



SCX-EB 4.5 LCD



SMRT-EB

SOLID STATE SENSORS

A

SenSym

SECTION A

NEW PRODUCTS

SECTION TABLE OF CONTENTS

Amplified SCX Series

SCXL010DN

SCX-EB 4.5 LCD

SLP010D

SOC Series

SSC Series

A-3

A-8

A-12

A-16

A-19

A-22

SOLID STATE SENSORS

SenSym

SenSym

AMPLIFIED SCX SERIES

0 to 1 psi to 0 to 150 psi
SIGNAL CONDITIONED PRESSURE SENSORS

PRELIMINARY

EXPECTED AVAILABILITY
Q4, 1993

A

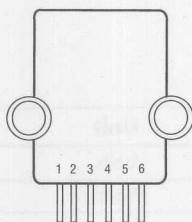
FEATURES

- 5 Volt Supply
- High Level Voltage Output
- Field Interchangeable
- Calibrated and Temperature Compensated
- Small Form Factor

APPLICATIONS

- Medical Equipment
- Industrial Controls
- Pneumatic Equipment

ELECTRICAL CONNECTION



- Pin 1. External Offset Adj.
Pin 2. V_s
Pin 3. Output (+)
Pin 4. Ground
Pin 5. N/C
Pin 6. External Offset Adj.

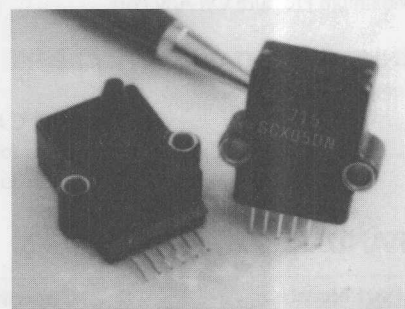
GENERAL DESCRIPTION

This series is a signal conditioned version of SenSym's proven performer and industry leading SCX series.

The amplified version is in a package with the same footprint as the SCX and provides a high level output (4.5V span) on a very cost effective basis. This family is temperature compensated over the range of 0°C to 70°C but can be operated from -40°C to +85°C. Like the companion SCX Series, these sensors are intended for use with non-corrosive, non-ionic working fluids; such as, air and dry gasses.

Devices are available to measure absolute, differential, and gage pressures from 1 psi (ASCX01) to 150 psi (ASCX150). The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the pressure sensing diaphragm and can be used for gage or differential pressure measurements.

The Amplified SCX devices feature an integrated circuit sensor element and laser trimmed thick film ceramic housed in a compact nylon case. This package provides excellent corrosion resistance and provides isolation to external package stresses. The package has convenient mounting holes and pressure ports for ease of use with standard plastic tubing for pressure connection.



All ASCX devices are calibrated for span to within $\pm 1\%$ (typically $\pm 0.2\%$) of FSO. Typical offset is 0.25V but provision is made to connect an external offset adjustment pot across pins 1 and 6.

The output is ratiometric to the supply voltage and operation from any D.C. supply from +5V to +16V is acceptable.

Because these devices have very low noise and excellent temperature compensation, they are ideal for medical and other high performance applications. The 100 microsecond response time also makes this series an excellent choice for computer peripherals and pneumatic control applications.

For further technical information on the Amplified SCX series, please contact your local SenSym office or the factory.

PRESSURE SENSOR CHARACTERISTICS**MAXIMUM RATINGS**

Supply Voltage, V_S	+5.0V _{DC} to +16V _{DC}
Output Current	
Source	10mA
Sink	10mA
Lead Temperature (10 sec)	300°C
Maximum Pressure On Any Port	150 psi

PARAMETER REFERENCE CONDITIONS

Supply Voltage	5.01 ± 0.01V _{DC}
Reference Temperature	25°C
Load Condition	200 Kohms
Common-Mode Pressure	0 psig

ENVIRONMENTAL SPECIFICATIONS

Temperature Ranges	
Compensated	0°C to 70°C
Operating	-25°C to 105°C
Storage	-55°C to 125°C

STANDARD PRESSURE RANGES

Part Number	Operating Pressure	Proof Pressure*	Sensitivity
ASCX01DN	0 – 1 psid	20 psid	4.5V/psi
ASCX05DN	0 – 5 psid	20 psid	0.9V/psi
ASCX15AN	0 – 15 psia	30 psia	0.3V/psi
ASCX15DN	0 – 15 psid	30 psid	0.3V/psi
ASCX30AN	0 – 30 psia	60 psia	0.15V/psi
ASCX30DN	0 – 30 psid	60 psid	0.15V/psi
ASCX100AN	0 – 100 psia	150 psia	45mV/psi
ASCX100DN	0 – 100 psid	150 psid	45mV/psi
ASCX150AN	0 – 150 psia	150 psia	30mV/psi
ASCX150DN	0 – 150 psid	150 psid	30mV/psi

*Maximum Pressure above which causes permanent sensor failure.

AMPLIFIED SCX PERFORMANCE CHARACTERISTICS (For All Devices) ⁽¹⁾

Characteristic	Min.	Typ.	Max.	Unit
Offset ⁽²⁾	0.205	0.250	0.295	Volts
Span (FSO) ⁽³⁾	4.455	4.500	4.545	Volts
Output @ FS Pressure	4.660	4.750	4.840	Volts
Linearity & Hysteresis ⁽⁴⁾	—	±0.1	±0.5	%FSO
Span TC (0°C to 70°C)	—	±0.2	+1.0	%FSO
Offset TC (0°C to 70°C)	—	±0.5	+1.0	%FSO
Repeatability ⁽⁵⁾	—	±0.2	±0.5	%FSO
Response Time ⁽⁶⁾	—	0.1	1.0	ms

Specification Notes:

Note 1: Performance specifications shown are at reference conditions. Specifications apply for absolute pressure devices with pressure applied to Port 1. For gage devices pressure is applied to Port 2 and Port 1 is left open to ambient. For differential pressures, Port 2 is the high pressure port. All SenSym differential devices feature dual pressure ports and can be used as gage or differential sensors. For absolute devices, Port 2 is inactive.

Note 2: Offset calibration is at the lowest pressure for each given device.

Note 3: Full-scale span is the algebraic difference between the output voltage at full-scale pressure and the output at the lowest operating pressure.

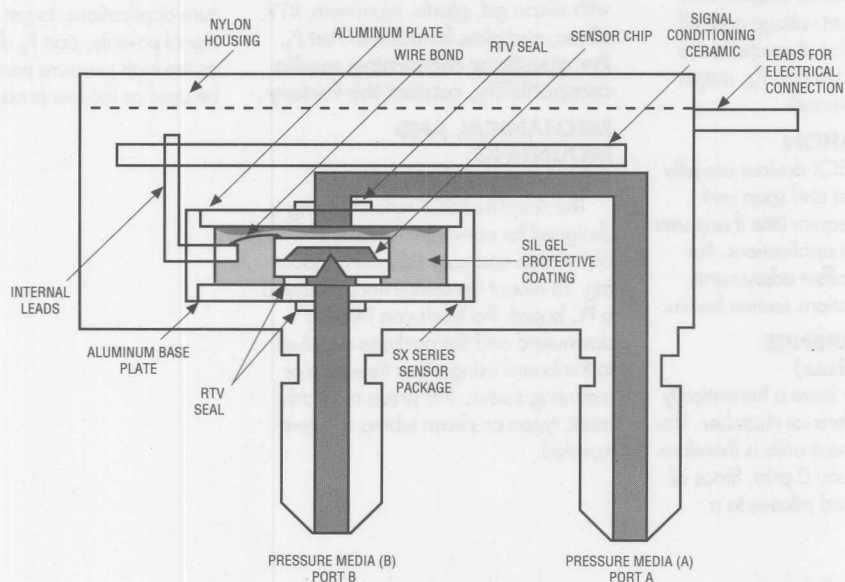
Note 4: Linearity refers to the best straight line fit as measured for offset, full-scale and 1.2 full-scale pressure.

Note 5: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +70°C after:

a) 100 temperature cycles, 0°C to +70°C

b) 1.0 million pressure cycles, 0 psi to full-scale span.

Note 6: Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time.

A

Physical Construction (Cutaway Diagram — Not drawn to scale)

GENERAL DISCUSSION

The Amplified SCX series devices a give voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port PB of the device. If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage will cause proportional changes in the offset voltage and full-scale span. Since for absolute device pressure is applied to port P_A, output polarity will be reversed.

USER CALIBRATION

The Amplified SCX devices are fully calibrated for offset and span and should therefore require little if any user adjustment in most applications. For precise span and offset adjustments, refer to the applications section herein.

VACUUM REFERENCE (Absolute Devices)

Absolute sensor have a hermetically sealed vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a

vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

MEDIA COMPATIBILITY

Amplified SCX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective silicon gel, many otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below, fluids must generally be compatible with silicon gel, plastic, aluminum, RTV, silicon, and glass for use with Port P_B.

For questions concerning media compatibility, contact the factory.

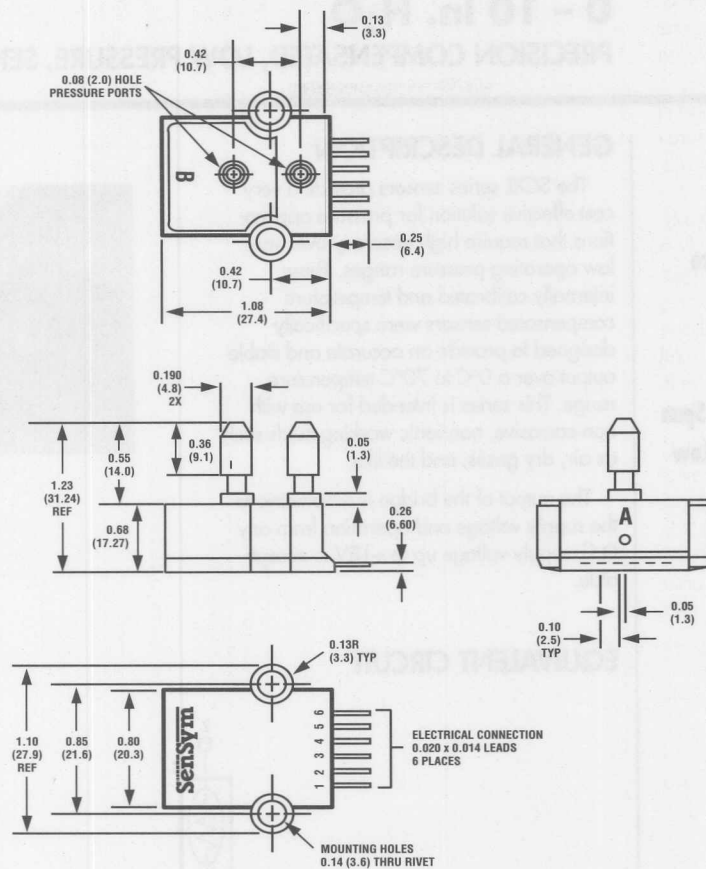
MECHANICAL AND MOUNTING CONSIDERATIONS

The Amplified SCX nylon housing is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

All versions of the Amplified SCX sensors have two (2) tubes available for pressure connection. For absolute devices, only port P_A is active. Applying pressure through the other port will result in pressure dead ending into the backside of the silicon sensor and the device will not give an output signal with pressure.

For gage applications, pressure should be applied to port P_B. Port P_A is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port P_B should be used as the high pressure port and P_A should be used as the low pressure port.

PHYSICAL DIMENSIONS



A

ORDERING INFORMATION

To order, use the following part number(s):

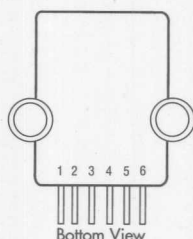
Description	Part Number
0 to 1 psi Differential/Gage	ASCX01DN
0 to 5 psi Differential/Gage	ASCX05DN
0 to 15 psi Absolute	ASCX15AN
0 to 15 psi Differential/Gage	ASCX15DN
0 to 30 psi Absolute	ASCX30AN
0 to 30 psi Differential/Gage	ASCX30DN
0 to 100 psi Absolute	ASCX100AN
0 to 100 psi Differential/Gage	ASCX100DN
0 to 150 psi Absolute	ASCX150AN
0 to 150 psi Differential/Gage	ASCX150DN

SenSym**SCXL010DN****0 - 10 In. H₂O****PRECISION COMPENSATED, LOW PRESSURE, SENSORS****PRELIMINARY**EXPECTED AVAILABILITY
Q4, 1993**FEATURES**

- Very Low Pressure Resolution
- Precision Temperature Compensation
- Small Size
- Low Noise
- Calibrated Zero and Span
- High Impedance for Low Power Applications

APPLICATIONS

- Air Flow
- Respirators
- HVAC

ELECTRICAL CONNECTION

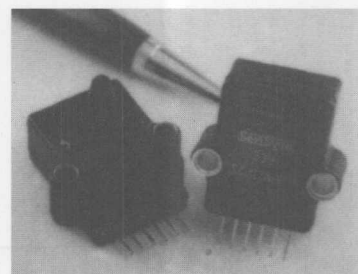
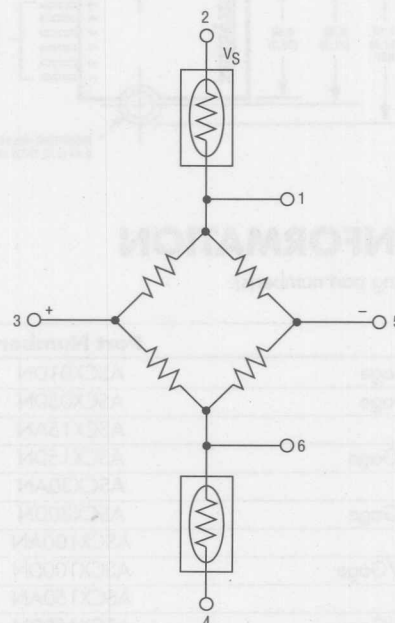
- Pin 1. Temperature Output (+)
Pin 2. V_s
Pin 3. Output (+)
Pin 4. Ground
Pin 5. Output (-)
Pin 6. Temperature Output (-)

Note: The polarity indicated is for pressure applied to port B

GENERAL DESCRIPTION

The SCXL series sensors provide a very cost effective solution for pressure applications that require high accuracy over very low operating pressure ranges. These internally calibrated and temperature compensated sensors were specifically designed to provide an accurate and stable output over a 0°C to 70°C temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

The output of the bridge is ratiometric to the supply voltage and operation from any D.C. supply voltage up to +18V is acceptable.

**EQUIVALENT CIRCUIT**

PRESSURE SENSOR CHARACTERISTICS**MAXIMUM RATINGS**

Supply Voltage, V_S	+18V _{DC}
Common-mode Pressure	150 In. H ₂ O
Lead Temperature (Soldering, 10 seconds)	300°C
Burst Pressure	5 psi

ENVIRONMENTAL SPECIFICATIONS

Temperature Ranges	
Compensated	0°C to 70°C
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Humidity Limits	0 to 80% RH

SCXL010DN PERFORMANCE CHARACTERISTICS (1)

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range	—	—	10	In. H ₂ O
Sensitivity	—	5.0	—	mV/In. H ₂ O
Full-scale Span ⁽²⁾	49	5.0	51	mV
Zero Pressure Offset	-1.0	0	+1.0	mV
Combined Linearity and Hysteresis ⁽³⁾	—	±0.5	±1.0	%FS
Temperature Effect on Span (0°C–70°C) ⁽⁴⁾	—	±0.5	±1.0	%FS
Temperature Effect on Offset (0°C–70°C) ⁽⁴⁾	—	±0.5	±1.0	mV
Repeatability ⁽⁵⁾	—	±0.2	—	%FS
Input Impedance ⁽⁶⁾	—	4.0	—	kΩ
Output Impedance ⁽⁷⁾	—	4.0	—	kΩ
Common-mode Voltage ⁽⁸⁾	5.7	6.0	6.3	V _{DC}
Response Time ⁽⁹⁾	—	500	—	μs
Long Term Stability of Offset and Span ⁽¹⁰⁾	—	±0.5	—	%FS
Proof Pressure ⁽¹¹⁾	—	10	—	In. H ₂ O

SPECIFICATION NOTES:

- Note 1: Reference Conditions: Unless otherwise noted: Supply Voltage, $V_S=12V$, $T_A=25^\circ C$, Common-mode Line Pressure=0 psig, Pressure Applied to Port B.
- Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Span is ratiometric to the supply voltage.
- Note 3: Zero pressure effect is measured with pins pointed towards the ground. Offset can be position sensitive.
- Note 4: Maximum error band of the offset voltage and the error band of the span, relative to the 25°C reading.
- Note 5: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +70°C after:
- 100 temperature cycles, 0°C to 70°C
 - 1.0 million pressure cycles, 0 psi to full-scale span.
- Note 6: Input impedance is the impedance between pins 2 and 4.
- Note 7: Output impedance is the impedance between pins 3 and 5.
- Note 8: This is the common-mode voltage of the output arms (Pins 3 and 5) for $V_S=12V$.
- Note 9: Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time
- Note 10: Long term stability over a one year period.
- Note 11: Proof pressure is the pressure above which devices will not return to guaranteed specifications.

GENERAL DISCUSSION

The SCXL series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port B of the device. If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage and full-scale span.

USER CALIBRATION

The SCXL devices are fully calibrated for offset and span and should therefore require little user adjustment in

most applications. For precise span and offset adjustments, refer to the applications section herein or contact the Sensym factory.

MEDIA COMPATIBILITY

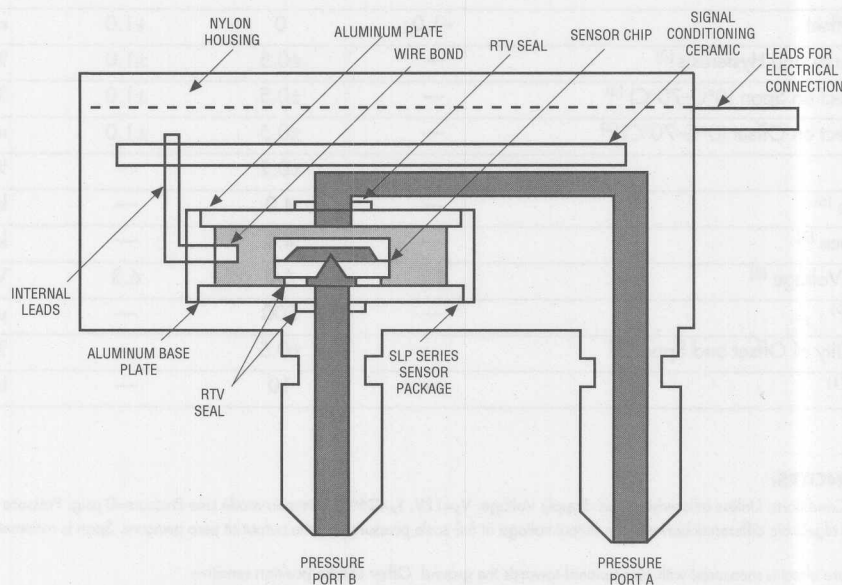
SCXL devices are intended for use with non-corrosive gases. As shown in the physical construction diagram below, fluids must generally be compatible with plastic, aluminum, RTV, silicon, and glass for use with Port B. For questions concerning media compatibility, contact the factory.

MECHANICAL AND MOUNTING CONSIDERATIONS

The SCXL nylon housing is designed for convenient pressure connection and

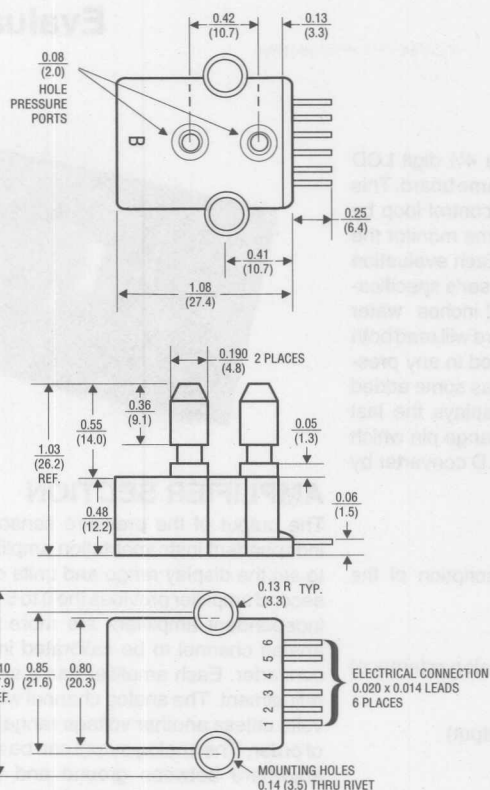
easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicone tubing is recommended.

All versions of the SCXL sensors have two (2) tubes available for pressure connection. For gage applications, pressure should be applied to port B. Port A is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port B should be used as the high pressure port and A should be used as the low pressure port.



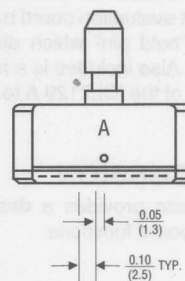
Physical Construction (Cutaway Diagram — Not drawn to scale)

PHYSICAL DIMENSIONS



DIMENSIONS IN INCHES (MILLIMETERS)
WEIGHT: 5 GRAMS
CASE MATERIAL: GLASS FILLED NYLON

WETTED MATERIAL
PORT A: GLASS FILLED NYLON, RTV, SILGEL
PORT B: GLASS FILLED NYLON, SILICON, RTV
SEE PHYSICAL CONSTRUCTION DRAWING



A

ORDERING INFORMATION

To order, use the following part number(s):

Description	Part Number
0 to 10 In. WC	SCXL010DN

INTRODUCTION

The 4½ digit evaluation board combines a 4½ digit LCD display with a 0 to 5V analog output on the same board. This combination allows the user to close the control loop by digitizing the 5V output and at the same time monitor the system pressure on the 4½ digit display. Each evaluation board is assembled and calibrated to the user's specifications. Any pressure from a minimum of 2 inches water column to 500 psi can be specified. The board will read both pressure and vacuum and can be calibrated in any pressure units. The 4½ digit evaluation board has some added features; such, as a "hold pin" which displays the last reading until released. Also included is a range pin which reduces the sensitivity of the ICL7129 A to D converter by a factor of 10.

GENERAL DISCUSSION

The following discussion provides a description of the separate 4½ digit EB board functions:

1. Pressure sensor
2. 5 volt reference (sensor excitation & analog reference)
3. ICL7129 A/D converter and display.
4. Instrumentation Amplifier (0 to 5 volt output)
5. 1 uncommitted Operational Amplifier
6. Breadboard area

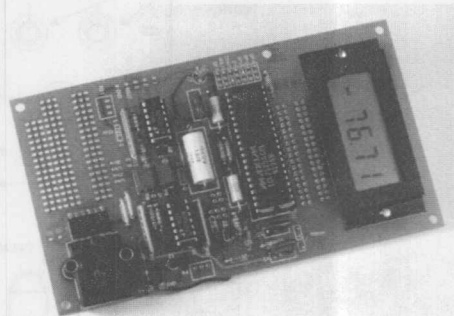
PRESSURE SENSOR

THE 4½ digit EB board has been designed to operate with any SenSym SCX series pressure sensor, as well as any isolated stainless SSX series sensor. An SCX C series sensor is included in the price of the board. The sensor can be upgraded to a stainless steel (SSX), or a prime SCX series sensor for an additional fee.

POWER SUPPLY AND REFERENCE VOLTAGE

The circuit is designed to operate on a 9 volt supply voltage, the supply limits are 7 to 15 volts. The typical quiescent current at 9 volts is 6.0 mA. The low battery indicator will be displayed when the supply voltage drops to less than 7V.

Amplifier A1 pin 14 amplifies the 2.5V band gap zener to 5 volts which is the reference voltage for the sensor and analog circuitry.



AMPLIFIER SECTION

The output of the pressure sensor is amplified by two independent instrumentation amplifiers. One is calibrated to set the display range and units of the LCD display, the second amplifier provides the 0 to 5 volt analog output. Two independent amplifiers are more flexible and allow the analog channel to be calibrated independent of the A/D converter. Each amplifier has a separate offset and gain adjustment. The analog channel will be calibrated to 0 to 5 volts unless another voltage range is specified at the time of order. The analog output can be adjusted to have a span anywhere between ground and (V+ - 2V). Since the evaluation board has been designed to operate on a single positive supply the analog output is limited to positive outputs. Differential applications can be biased at 2.5V and swing from 0 to 5 volts for plus and minus pressures. Both amplifier stages have the same gain equation as shown below:

$$A_V = \frac{V_O}{V_{IN}} = \left[2 \left(1 + \frac{R_F}{R_g} \right) \right] \quad (1)$$

where:

$$R_F = 100k$$

$$R_g = R_3 + R_4 \text{ or } R_{21} + R_{22}$$

The equation for calculating R_g :

$$R_g = \frac{2 R_F}{A_V - 2} \quad (2)$$

As seen from the equation the minimum gain of the amplifier ($R_g = \text{infinite}$) is two.

4½ Digit & 0 – 5V Evaluation Board

UNCOMMITTED AMPLIFIER AND BREADBOARD AREA

Amplifier A2 is available to the user for breadboarding purposes. If the board is used in an excessively noisy environment pins 1 & 2 should be shorted and pin 3 grounded. The lower left hand corner of the PC board has been designed for a breadboard area. Traces A through E have been added to the board for breadboarding convenience. The function of these traces are as follows:

- A = Connected to the 2V range pin. A peak detector or other customer designed circuit could be breadboarded and used to control the A/D gain.
- B = Connected to the A/D in Hi pin.
- C = Connected to the Instrumentation amplifier output.
- D = Connected to the A/D in Lo pin.
- E = Connected to the offset adjust amplifier output.

The traces can be used to insert circuits between the instrumentation amplifier and the A/D Converter. Trace C could be connected to amplifier A1 output and make that signal available at the breadboard area. Trace B could be jumpered to the A/D input and carry the signal from the breadboard area to the A/D. The trace between the two jumper solder pads will have to be cut (opened). Traces E and D can be used to perform the same function between the amplifier A1 and pin 32 (in lo).

JUMPER OPTIONS

The output voltage polarity of absolute SCX "A" sensors is inverted when compared to the differential SCX "D" series sensors. Jumpers J1 through J4 are provided to invert the absolute sensor output and give a positive reading for a positive going pressure.

Differential Sensor = J1 & J3 shorted, J2 & J4 open

Absolute Sensor = J2 & J4 shorted, J1 & J3 open

Two solder pads have been provided in the traces from the sensor to amplifier A2 pins 12 and 3. These pads can be used to invert or modify just the analog channel (J1 through J4 inverts both channel).

Any one of the four decimal points can be turned on by installing the appropriate jumper.

JUMPER	DECIMAL POINT
DP 1	1999.9
DP 2	199.99
DP 3	19.999
DP 4	1.9999

Installing the 2V (pulled high) jumper reduces the sensitivity by a factor of 10.

Pulling the hold pin high forces the last displayed reading to be held. A FET switch can be used to control the hold pin. When it is left open the A/D will free run.

MOUNTING OPTIONS

The 4½ digit evaluation board can be used as a portable pressure meter or incorporated into a larger system. The display portion of the board can be cut off just below the LCD and mounted on a panel. A 16 conductor ribbon cable would be used to connect the two boards.

DESIGN EXAMPLE

The following example will discuss the step by step procedure to modify the 4½ digit evaluation board to measure 0 to 20 inches of water column.

Sensor Selection, (1 psi = 27.68 inches of water) The SCX01DNC will be used for 20" H₂O. For 20" H₂O the sensor output will be determined as follows:

$$\begin{aligned} 5/12 \times 18 \text{ mV} &= 7.5 \text{ mV} / \text{psi}^*, \\ 7.5 / 27.68 &= 270.95 \text{ microvolts/in.} \end{aligned}$$

$$270.95 \times 20 = 5.419 \text{ mV} / 20 \text{ in H}_2\text{O}$$

The sensor output is 5.419mV for 20 inch of water pressure input.

The next step is to determine the amplifier gain, R3 & R4 are selected as follows. The 7129 wants to see 200mV on the input to give 19999.

$$200 \text{ mV} / 5.419 \text{ mV} = 36.907$$

The amplifier needs a gain of 36.9, using equation 2 the combined impedance of R3 & R4 should be:

$$200 \text{ K} / 36.907 - 2 = 5.729 \text{ K}$$

R3 = 4.99K and R4 = 2K pot.

The gain resistors for the 0 to 5 volt amplifier are calculated in the same manner:

$$5 \text{ V} / 5.419 \text{ mV} = 922.7$$

$$200 \text{ K} / 922.7 - 2 = 217 \text{ ohms}$$

R22 = 200 ohms and R21 = 50 ohms.

The next step is to install the correct jumpers.

DP1 = OFF

DP2 = OFF

DP3 = ON (19.999 on display)

DP4 = OFF

2V = OFF

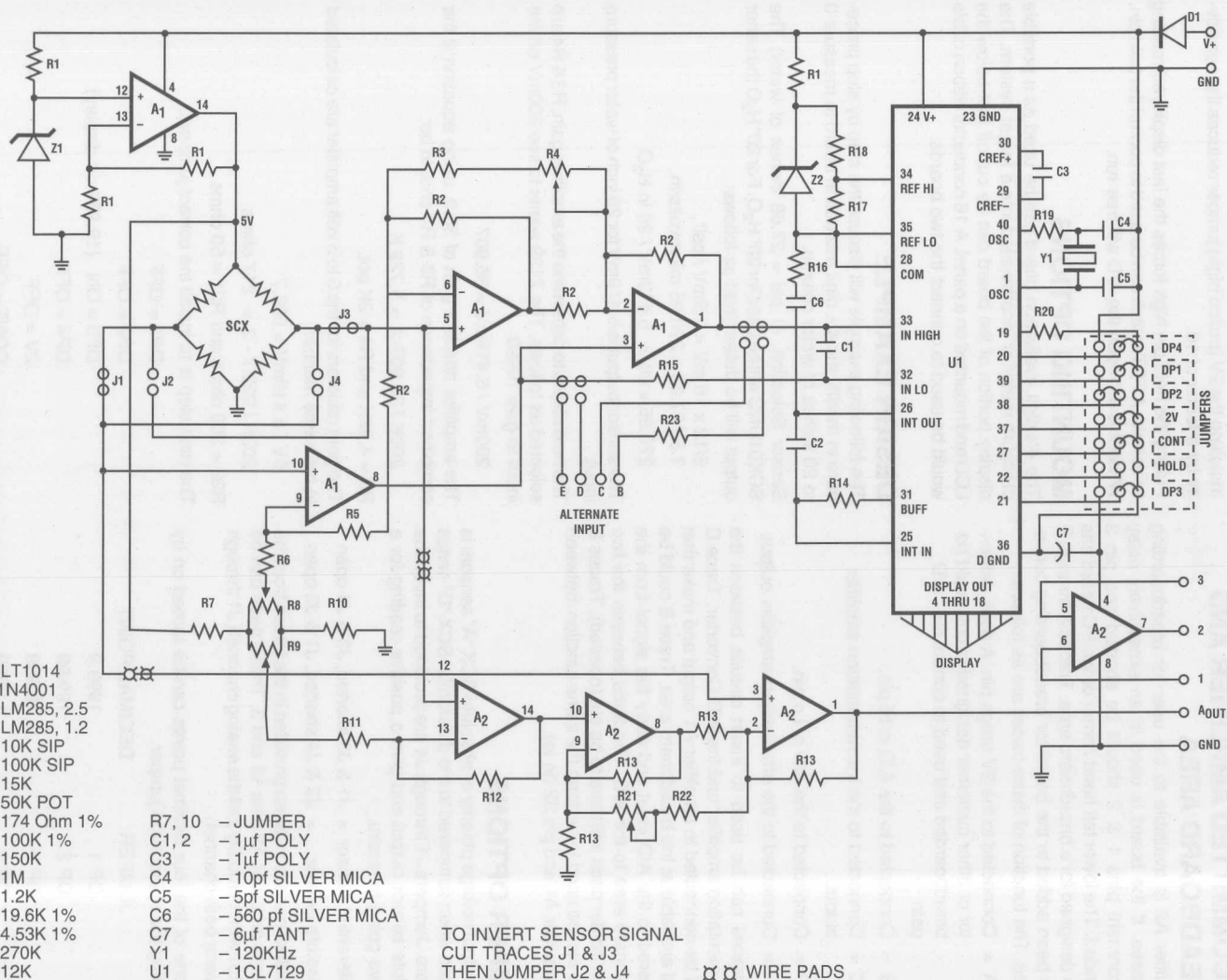
CONT = OFF

*18mV is the standard sensitivity of a 1 psi part at 12 volts. In this application the sensor is powered by 5 volts.

SCX-EB 4.5 LCD Schematic

A-14

- | | | | |
|---------------|--------------|--------|----------------------|
| A1, 2 | - LT1014 | R7, 10 | - JUMPER |
| D1 | - 1N4001 | C1, 2 | - 1µf POLY |
| Z1 | - LM285, 2.5 | C3 | - 1µf POLY |
| Z2 | - LM285, 1.2 | C4 | - 10pf SILVER MICA |
| R1 | - 10K SIP | C5 | - 5pf SILVER MICA |
| R2, 13 | - 100K SIP | C6 | - 560 pf SILVER MICA |
| R3, 4, 21, 22 | - 15K | C7 | - 6µf TANT |
| R8, 9 | - 50K POT | Y1 | - 120KHz |
| R5, 12 | - 174 Ohm 1% | U1 | - 1CL7129 |
| R6, 11 | - 100K 1% | | |
| R14 | - 150K | | |
| R15 | - 1M | | |
| R16 | - 1.2K | | |
| R17 | - 19.6K 1% | | |
| R18 | - 4.53K 1% | | |
| R19 | - 270K | | |
| R20 | - 12K | | |



4½ Digit & 0 – 5V Evaluation Board

CALIBRATION

With no pressure applied to the sensor adjust R8 for a 0.000 reading on the display, adjust R9 for 50 millivolts output at the analog output.

Apply 20 inches of water pressure to the B port on the SCX01 and adjust R4 for a reading of 19.999 on the display, adjust R21 for %.0 volts output on the analog channel.

CONCLUSION

The 4½ digit evaluation board is the first dual function evaluation board in the series. The analog channel can be used to drive a recording device or interface to a computer while the LCD display provides a real time reading of the pressure. We hope this design will aid in the development of computer controlled pressure systems. If you have any questions regarding this or any evaluation board please contact our applications group at the SenSym factory.

A

SenSym

SLP010D 0 - 10 In. H₂O

LOW PRESSURE SENSORS

PRELIMINARY

EXPECTED AVAILABILITY
Q4, 1993

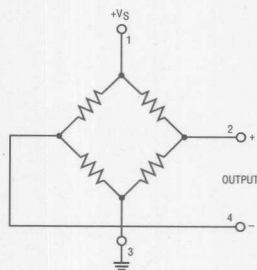
FEATURES

- Accurate Low Pressure Readings
- Low Cost
- High Impedance Bridge
- Low Noise
- Low power Consumption for Battery Operation

APPLICATIONS

- Medical Instrumentation
- Portable and Battery Powered Equipment
- Air Flow Monitoring
- HVAC
- Industrial Controls

EQUIVALENT CIRCUIT



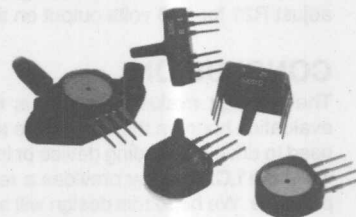
Note: Polarity applies for positive pressure applied to port, P2

GENERAL DESCRIPTION

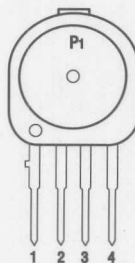
The SLP Series of pressure sensors provides the lowest cost components for measuring very low pressures. These low pressure range devices were specifically designed to accurately measure differential and gage pressures of 0 to 10 inches of H₂O. They are meant for use with non-corrosive and non-ionic media, such as air, dry gases and the like.

These differential devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

For further technical information on the SLP Series, please contact the factory.

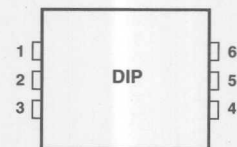


ELECTRICAL CONNECTIONS



- | | |
|--------------------|-------------|
| 1) +V _S | 2) + OUTPUT |
| 3) GROUND | 4) - OUTPUT |

BUTTON PACKAGE



- | | |
|----------------------|---------------|
| 1) -V _{OUT} | 2) GROUND |
| 3) +V _{OUT} | 4) No Connect |
| 5) V _S | 6) No Connect |

DIP PACKAGE

ABSOLUTE MAXIMUM RATINGS (For All Devices)

Supply Voltage (V)	7.5V _{DC}
Temperature Ranges	
Operating	-25°C to +85°C
Storage	-55°C to +125°C
Common-mode Pressure	150 In. H ₂ O
Lead Temperature	
(Soldering, 10 seconds)	300°C
Burst Pressure ⁽⁹⁾	5 psi or 150 In. H ₂ O

A

SLP010D PERFORMANCE CHARACTERISTICS ⁽¹⁾

Characteristic	Typ.	Unit
Operating Pressure	10	In. H ₂ O
Sensitivity T _A =25°C	1.0	mV/V/In. H ₂ O
Full-scale Span 10 In. H ₂ O ⁽²⁾	+50	mV
Temperature Coefficient of Span ^(5, 8)	-2400	ppm/°C
Zero Pressure Offset T _A =25°C	0	mV
Temperature Coefficient of Offset ⁽⁵⁾	±4	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁷⁾	0.1	%FS
Response Time (10% to 90%) ⁽⁶⁾	0.5	ms
Input Resistance T _A =25°C	4	kΩ
Temperature Coefficient of Resistance ^(5, 8)	+3300	ppm/°C
Output Impedance	4	kΩ
Repeatability ⁽⁴⁾	0.5	%FS
Position Sensitivity	50	μV/V/g

SPECIFICATION NOTES: (FOR ALL DEVICES)

Note 1: Reference Conditions: Supply Voltage, V_S=5V_{DC}, T_A=25°C, Common-mode Line Pressure=0 psig, Pressure Applied to P2.

Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.

Note 3: See Definition of Terms.

Hysteresis—the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.

Note 4: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +70°C after:

a) 100 temperature cycles, 0°C to 70°C

b) 1.0 million pressure cycles, 0 psi to full-scale span.

Note 5: Slope of the best straight line from 0°C to 70°C. For operation outside this temperature, contact factory for more specific applications information.

Note 6: Response time for a 0 psi to full-scale span pressure step change. 10% to 90% Rise Time

Note 7: Long term stability over a one year period.

Note 8: This parameter is not 100% tested. It is guaranteed by process design and tested on a sample basis only.

Note 9: If the maximum burst pressure is exceeded, even momentarily, the package may leak or burst, or the pressure sensing die may fracture.

ORDERING INFORMATION

To order, use the following part numbers:

Pressure Range	Package Options		
	Sensor In Button Sensor Package	Sensor In Nipple Package	Sensor In DIP Package
0 to 10 In. H ₂ O	SLP010D	SLP010DP1, 2	SLP010DD1, 2, 3

See Section 9 for Package Styles and Dimensions

SenSym

SOC SERIES 0 to 1 psi to 0 to 100 psi

THIN FILM COMPENSATED SENSORS

PRELIMINARY

EXPECTED AVAILABILITY
Q4, 1993

A

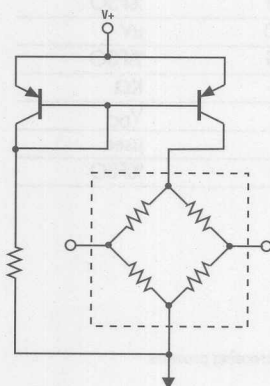
FEATURES

- Button and DIP Packages
- Extremely Small Size
- On-Chip Temperature Compensation
- On-Chip Calibrated Zero and Span
- Low Noise
- High Impedance

APPLICATIONS

- Medical Equipment
- Barometry
- Computer Peripherals
- Pneumatic Controls
- HVAC

EQUIVALENT CIRCUIT

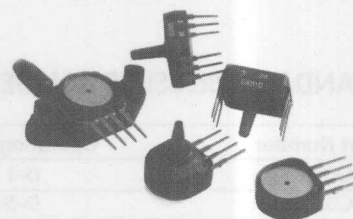


GENERAL DESCRIPTION

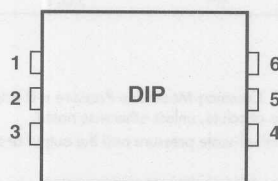
The SOC Series parts are designed for applications where an accurate, fully calibrated and compensated sensor is needed in a very small package. These devices feature thin-film, on-chip, laser trimmed, pressure sensors housed in a small DIP or "button" package. Devices provide an accurate and stable output over 0°C to 70°C. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

This design supports a family of sensors for measuring absolute, gage, and differential pressures from 0 to 1 psi up through 0 to 100 psi.

These sensors are designed to be used with 5 volt supplies. Because the devices have very low noise and excellent temperature compensation, they are ideal for medical and other high performance applications. The high impedance and small size makes this part an ideal choice for portable and battery operated applications.

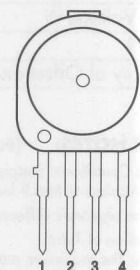


ELECTRICAL CONNECTIONS



- | | |
|---------------|---------------|
| 1) $-V_{OUT}$ | 2) GROUND |
| 3) $+V_{OUT}$ | 4) No Connect |
| 5) V_S | 6) No Connect |

DIP PACKAGE



- | | |
|-----------|---------------|
| 1) GROUND | 2) $-V_{OUT}$ |
| 3) $-V_S$ | 4) $+V_{OUT}$ |

BUTTON PACKAGE

PHYSICAL CHARACTERISTICS (For All Devices)**OPERATING CONDITIONS**

Supply Voltage, V_S	4.75 to 5.25V _{DC}
Supply Current (Max.)	2.0mA

ENVIRONMENTAL SPECIFICATIONS**Temperature Ranges**

Compensated	0°C to +70°C
Operating	-40°C to +85°C
Storage	-55°C to +125°C

Humidity Limits

0 to 100% RH

Maximum Pressure at any Port 150 psig**STANDARD PRESSURE RANGES**

Part Number	Operating Pressure	Proof Pressure*	Sensitivity
SOC01Dxx	0-1 psid	20 psid	25mV/psid
SOC05Dxx	0-5 psid	20 psid	10mV/psid
SOC15Axx	0-15 psia	30 psia	3.33mV/psia
SOC15Dxx	0-15 psid	30 psid	3.33mV/psid
SOC30Axx	0-30 psia	60 psia	1.67mV/psia
SOC30Dxx	0-30 psid	60 psid	1.67mV/psid
SOC100Axx	0-100 psia	150 psia	0.50mV/psia
SOC100Dxx	0-100 psid	150 psid	0.50mV/psid

* Maximum pressure above which causes permanent sensor failure.

PERFORMANCE CHARACTERISTICS (1)

Characteristic	Min.	Typ.	Max.	Unit
Full-Scale Span ^(2,9)	49.5	50.0	50.5	mV
Zero Pressure Offset	-500	0	+500	μV
Combined Linearity & Hysteresis ⁽³⁾	—	±0.1	±0.5	%FSO
Temperature Effect on Span (0°C to 70°C) ⁽⁴⁾	—	±0.2	±1.0	%FSO
Temperature Effect on Offset (0°C to 70°C) ⁽⁴⁾	—	±100	±500	μV
Repeatability ⁽⁵⁾	—	±0.2	±0.5	%FSO
Output Impedance	—	—	5.0	KΩ
Common-Mode Voltage ⁽⁶⁾	—	1.5	—	V _{DC}
Response Time ⁽⁷⁾	—	100	—	μsec
Long Term Stability of Offset and Span ⁽⁸⁾	—	±0.1	—	%FSO

SPECIFICATION NOTES: (For All Devices)

Note 1: Reference Conditions: Supply Voltage, $V_S = 5V_{DC}$, $T_A = 25^\circ\text{C}$ Common-Mode Line Pressure = 0 psig, Pressure Applied to Port B for gauge pressures and Port A for absolute, unless otherwise noted.

Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.

Note 3: See Definition of Terms.

Hysteresis: The maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.

Note 4: Maximum error band of the offset voltage and the error band of the span, relative to the 25°C reading.

Note 5: Maximum difference in output at any pressure within the operating pressure range and temperature within +0°C to +70°C after:

1) 100 temperature cycles, 0°C to +70°C.

2) 1.0 million pressure cycles, 0 psi to full-scale span.

Note 6: This is the common-mode voltage of the output arms for $V_S = 5V_{DC}$.

Note 7: Response time for a 0 psi to full-scale span pressure step change.

Note 8: Long term stability over a one year period.

Note 9: Full-scale output for the SOC01 devices will be 25mV ± 0.5mV.

PART NUMBERS

Package Options				
Pressure Range	DIP Package	Button	Single Port	Dual Ported (N)
0 to 1 psid	SOC01DD1,2,3	SOC01D	SOC01DP1,2	SOC01DN
0 to 5 psid	SOC05DD1,2,3	SOC05D	SOC05DP1,2	SOC05DN
0 to 15 psia	SOC15AD1,2,3	SOC15A	SOC15AP1,2	SOC15AN
0 to 15 psid	SOC15DD1,2,3	SOC15D	SOC15DP1,2	SOC15DN
0 to 30 psia	SOC30AD1,2,3	SOC30A	SOC30AP1,2	SOC30AN
0 to 30 psid	SOC30DD1,2,3	SOC30D	SOC30DP1,2	SOC30DN
0 to 100 psia	SOC100AD1,2,3	SOC100A	SOC100AP1,2	SOC100AN
0 to 100 psid	SOC100DD1,2,3	SOC100D	SOC100DP1,2	SOC100DN

A

See Section 9 for Package Styles and Dimensions

SenSym

SSC15, SSC30, SSC100, SSC150

0 to 15 psi to 0 to 150 psi

PRELIMINARY

LOW COST, STAINLESS STEEL PRESSURE SENSORS

EXPECTED AVAILABILITY
Q4, 1993

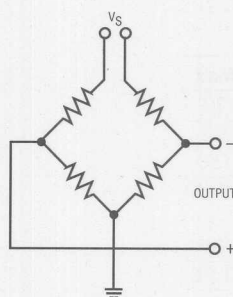
FEATURES

- Absolute or Gage Configuration
- Low Cost
- Rugged – Stainless Steel
- Reliable Semiconductor Technology

APPLICATIONS

- Energy Management
- Process Control
- Robotics
- Sewage and Water Treatment
- Hydraulics
- Off-Road Vehicles
- Agricultural

EQUIVALENT CIRCUIT



(Open Bridge)

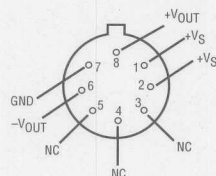
GENERAL DESCRIPTION

The stainless steel SSC Series devices were developed for pressure applications that involve measurement of a hostile media in harsh environments. These sensors will accommodate any media that will not adversely attack either 304 stainless steel or 316 stainless steel (used in the diaphragm). This series is made with SenSym's SX Series sensor die, which have proven to be highly reliable, stable and accurate.

The stainless steel case gives these parts excellent resistance to EMI and RFI. The devices feature a 1/8" male NPT fitting to allow easy connection to a variety of pressure connection fittings. These sensors are also available without a threaded fitting.

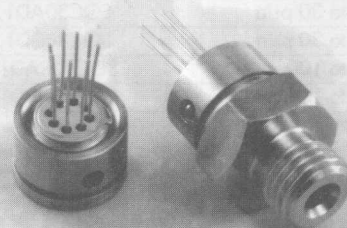
The SSC Series devices are rugged and reliable transducers for use in a wide variety of pressure sensing applications where corrosive liquids or gases are monitored. Contact your local SenSym representative or the SenSym factory for further details.

ELECTRICAL CONNECTION



Bottom View
(Open Bridge)

TO can Pinout



PRESSURE SENSOR CHARACTERISTICS

Maximum Ratings (For All Devices)

Supply Voltage, V_S	+12V _{DC}
Temperature Ranges	
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Lead Temperature (soldering 10 sec)	300°C
Maximum Pressure ⁽¹⁰⁾	
SSC15	30 psi
SSC30	60 psi
SSC100	150 psi
SSC150	200 psi

A

SSC15A/SSC15G PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	15	psi
Sensitivity $T_A = 25^\circ\text{C}$	1.0	1.5	2.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5%	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+590	+630	+670	ppm/°C
Output Impedance	—	4.5	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SSC30A/SSC30G PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	30	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.5	0.75	1.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5%	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+590	+630	+670	ppm/°C
Output Impedance	—	4.5	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SSC100A/SSC100G PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	100	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.2	0.3	0.4	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	100	150	200	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/ $^\circ\text{C}$
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	$\mu\text{V/V}/^\circ\text{C}$
Combined Linearity and Hysteresis ⁽³⁾	—	0.1	0.5%	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	k Ω
Temperature Coefficient of Resistance ^(6, 9)	+590	+630	+670	ppm/ $^\circ\text{C}$
Output Impedance	—	4.5	—	k Ω
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SSC150A/SSC150G PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	150	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.1	0.15	0.2	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/ $^\circ\text{C}$
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	$\mu\text{V/V}/^\circ\text{C}$
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5%	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	k Ω
Temperature Coefficient of Resistance ^(6, 9)	+590	+630	+670	ppm/ $^\circ\text{C}$
Output Impedance	—	4.5	—	k Ω
Repeatability ⁽⁴⁾	—	0.5	—	%FS

For a detailed General Discussion and Application Information for these sensors, please see Section 1 for the SX Series.

ORDERING INFORMATION

To order, use the following part numbers:

With Male Fitting

Part Number	Operating Pressure Range
SSC15MG, A	0 – 15 psig, a
SSC30MG, A	0 – 30 psig, a
SSC100MG, A	0 – 100 psig, a
SSC150MG, A	0 – 150 psig, a

A

As A Cell With No Fitting

Part Number	Operating Pressure Range
SSC15CG, A	0 – 15 psig, a
SSC30CG, A	0 – 30 psig, a
SSC100CG, A	0 – 100 psig, a
SSC150CG, A	0 – 150 psig, a

The SSC Series is available in two physical configurations. For package options and dimensions see Section 9.

SOLID STATE SENSORS

SenSym

ORDERING INFORMATION

To order, use the following key:

With Built-in Wiring

Part Number	Resistance
SECTION A	0 - 100 ohms
SECTION A	0 - 50 ohms
SECTION A	0 - 100 ohms
SECTION A	0 - 100 ohms
SECTION A	0 - 100 ohms

As A Cell With In-Wiring

Part Number	Resistance Range
SECTION A	0 - 10 ohms
SECTION A	0 - 50 ohms
SECTION A	0 - 100 ohms
SECTION A	0 - 100 ohms
SECTION A	0 - 100 ohms

The SSC Series is available in two physical configurations. For package options and dimensions see Section 2.

SOLID STATE SENSORS

SenSym

1

SECTION 1 BASIC SENSOR ELEMENTS

SECTION TABLE OF CONTENTS

SCC Series	1-3
SX Series	1-9
SPX Series	1-29
SLP004D	1-41
SCC "ISO" Series	1-45

SOLID STATE SENSORS

SenSym

SenSym

SCC SERIES 0 to 5, to 0 to 300 psi

PRESSURE SENSORS

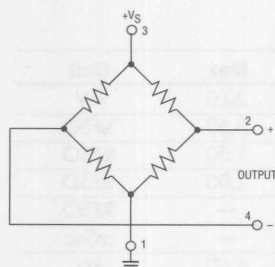
FEATURES

- Low Cost Sensor Element
- Internal Temperature Compensation
- Differential or Gage Pressures

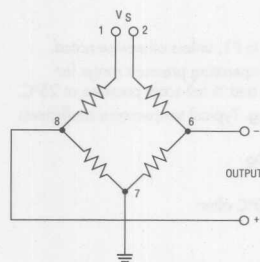
APPLICATIONS

- Pneumatic Controls
- Automotive Diagnostics
- Medical Equipment
- Dental Equipment
- Environmental Controls

EQUIVALENT CIRCUITS



Button Sensor or
"N" Package



(Open Bridge)

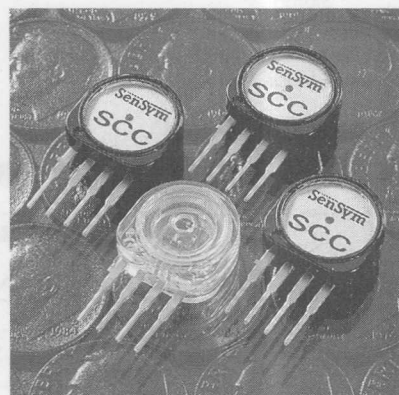
TO Can Package

GENERAL DESCRIPTION

The SCC series offer an extremely low cost sensor element with a temperature stable output when driven with a constant current source. These integrated circuit sensors were designed for extremely cost sensitive applications where precise accuracy over a wide temperature range is not required. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

Absolute devices have an internal vacuum reference and an output voltage proportional to applied pressure. The differential devices allow application of pressure to either side of the diaphragm and devices are thereby available to measure both differential and gage pressures.

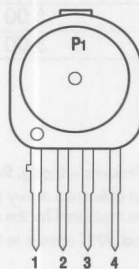
This product is packaged either in SenSym's standard low cost chip carrier "button" package or a metal TO can package. Both packages are designed for applications where the sensing element is to be integral to the OEM equipment. These



packages can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting. A closed bridge four-pin SIP configuration is provided for electrical connection to the button package. The TO can offers a 5-pin open bridge configuration.

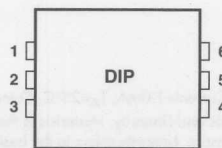
For further technical information on this series, please contact your local SenSym office or the factory.

ELECTRICAL CONNECTIONS



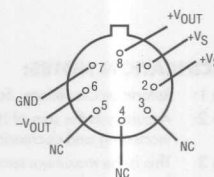
- | | |
|-----------|------------|
| 1) GROUND | 2) +OUTPUT |
| 3) +VS | 4) -OUTPUT |

Button Sensor



- | | |
|----------------------|---------------|
| 1) -V _{OUT} | 2) GROUND |
| 3) +V _{OUT} | 4) No Connect |
| 5) V _S | 6) No Connect |

DIP



Bottom View
(Open Bridge)

TO Can Pinout

NOTE: Polarity applies for positive pressure applied to the high pressure port, P₁.
TO Package only available in an Open Bridge configuration. See SCC "ISO" series for application information.

PRESSURE SENSOR CHARACTERISTICS

Maximum Ratings (For All Devices)

Supply Current, I_S	1.5mA
Temperature Ranges	
Compensated	0°C to +50°C
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Humidity	0 to 100% RH
Lead Temperature (soldering 10 sec)	300°C
Common-Mode Pressure	150 psi

PERFORMANCE CHARACTERISTICS (Individual Models) $I_S=1.0\text{mA}$, $T_A=25^\circ\text{C}$ (1)

Part #	Operating Pressure Range	Maximum Over Pressure	Accuracy ⁽²⁾	Effect On Span ⁽³⁾ (0°C–50°C)	Effect on Offset ⁽⁴⁾ (0°C–50°C)	Full-Scale Span ⁽⁵⁾ (mV)
SCC05(D, G)	0-5 psid (g)	20 psi	0.50%	1.50%	2.00%	25-65
SCC15A	0-15 psia	30 psia	0.50%	1.50%	2.00%	40-95
SCC15(D, G)	0-15 psid (g)	30 psi	0.50%	1.50%	2.00%	40-95
SCC30(D, G)	0-30 psid (g)	60 psi	0.50%	1.50%	2.00%	60-150
SCC100A	0-100 psia	150 psia	0.50%	1.50%	2.00%	85-225
SCC100(D, G) ⁽⁹⁾	0-100 psig	150 psig	0.50%	1.50%	2.00%	85-225
SCC300A	0-300 psia	450 psia	0.50%	1.50%	2.00%	50-120

PERFORMANCE CHARACTERISTICS (All Models) $I_S = 1.0\text{mA}$, $T_A = 25^\circ\text{C}$

Characteristics	Min	Typ	Max	Unit
Zero Pressure Offset	-30.0	-10	20.0	mV
Combined, Linearity, Hysteresis, Repeatability ⁽²⁾	—	0.25	0.50	%FSO
Temperature Effect on Span ^(3, 8)	—	0.25	1.50	%FSO
Temperature Effect on Offset ^(4, 8)	—	0.50	2.00	%FSO
Long Term Stability of Offset and Span ⁽⁶⁾	—	0.10	—	%FSO
Response Time (10% to 90%) ⁽⁷⁾	—	0.10	—	mSec
Input Impedance	4.00	5.00	6.50	k Ω
Output Impedance	4.00	5.00	6.50	k Ω

SPECIFICATION NOTES:

Note 1: Reference Conditions: Supply Current=1.0mA, $T_A=25^\circ\text{C}$, Common-mode Line Pressure = 0 psig, Pressure Applied to P1, unless otherwise noted.

Note 2: Accuracy is the sum of Hysteresis and Linearity. Hysteresis is the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure. Linearity refers to the best straight line fit as measured for the offset, full-scale and ½ full-scale pressure at 25°C.

Note 3: This is the maximum temperature shift for span when measured between 0°C and 50°C relative to the 25°C reading. Typical temperature coefficients for span and resistance are -2200ppm/°C and +2200ppm/°C respectively.

Note 4: This is the maximum temperature shift for offset when measured between 0°C and 50°C relative to the 25°C reading.

Note 5: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.

Note 6: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to 50°C after:

a) 100 temperature cycles, 0°C to 50°C.

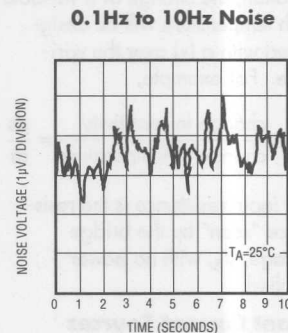
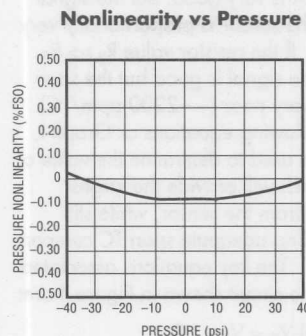
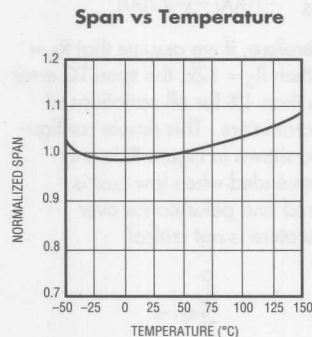
b) 1.0 million pressure cycles, 0 psi to full-scale span.

Note 7: Response time for a 0 psi to full-scale span pressure step change. 10% to 90% rise time.

Note 8: Temp effect on span and offset are guaranteed by design. Therefore these parameters are not 100% tested.

Note 9: The SCC100D devices can only be used in a forward gauge mode. Application of more than 30 psig to the back side of any of the SCC Series devices can result in device failure.

TYPICAL PERFORMANCE CHARACTERISTICS



1

APPLICATION INFORMATION

General Information

The SCC family of pressure sensors function as a wheatstone bridge. When pressure is applied to the device the resistors in the arms of the bridge change as shown in Figure 1.

The resulting differential output voltage, V_O , is easily shown to be $V_O = V_B \times R$. Since the change in resistance is directly proportional to pressure, V_O , can be written as:

$$V_O = S \times P \times V_B + V_{OS}$$

Where: V_O is the output voltage in mV

S is the sensitivity in mV/V psi

P is the pressure in psi

V_B is the bridge voltage in volts

V_{OS} is the offset error, (the differential output voltage when the applied pressure is zero).

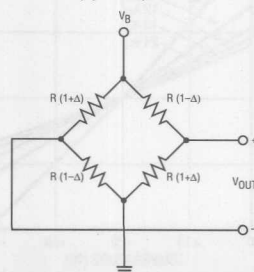


Figure 1. Button Sensor Bridge Schematic

The offset and sensitivity calibrations present little problem in most applications, as they can easily be corrected for in the amplification circuitry, or corrected digitally if a microprocessor is used in the system. Generally, it is the temperature errors which cause the greatest difficulty in using the basic sensor element.

Temperature Effects

The output voltage, V_O , will be equal to the product shown in equation 1 if the temperature is constant. However, a characteristic of all piezoresistive silicon pressure sensors, is a change in sensitivity over temperature.

From equation (1), ignoring the V_{OS} term, it is seen that for a constant pressure, the output voltage as a function of temperature, is:

$$\dot{V}_O = \dot{S}PV_B(1) + SP\dot{V}_B$$

As shown in the datasheet, the temperature coefficient of the span, TCS, is $-2200\text{ppm}/^\circ\text{C}$. Thus, in order for the output voltage to be independent of temperature, the voltage across the bridge, V_B , must change with temperature in equal magnitude but in the "opposite

direction" from the sensitivity change with temperature. Or in mathematical terms

$$\frac{\dot{V}_B}{V_B} = -\frac{\dot{S}}{S}$$

Although diode strings and transistor techniques can be used to temperature compensate the bridge (and in fact will be required for extended temperature operation) such techniques are difficult to use in volume production. For the SCC series a much simpler solution does exist as SenSym's SCC family of pressure sensors are manufactured such that the bridges input resistance², changes linearly at the rate of:

$$\frac{\dot{R}_B}{R_B} = 2200 \pm 200 \text{ ppm}/^\circ\text{C}$$

Therefore, if these devices are excited with a constant current source, the voltage across the bridge will increase with temperature as R_B increases, and thereby offset the decrease in sensitivity as shown below.

$$\begin{aligned} V_B &= R_B I \\ \frac{\dot{V}_B}{V_B} &= \frac{\dot{R}_B}{R_B} \end{aligned}$$

APPLICATION INFORMATION

- (1) In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a ($\bullet$) over the variable. For example,

$$\dot{S} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{ds}{dt}$$

- (2) The input resistance is the resistance "seen" by the bridge voltage, V_B , with no power applied.

Constant Current Sources

In order to optimize the SCC series performance over temperature, a constant current source must be constructed. The construction of such a device can be complex or straightforward depending on the temperature range and degree of accuracy required. The following are two of the recommended constant current sources for the SCC family.

Lowest Cost Constant Current Source

A very low cost current source solution is possible, if the temperature range is limited and the power supply voltage (V_S) is constant over temperature, by using a single resistor, R_S , in series with the bridge (R_B), as shown in Figure II.

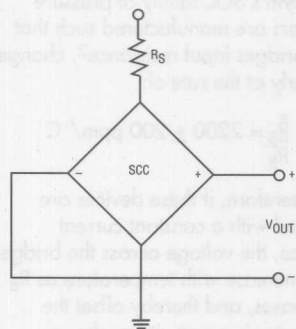


Figure II: Single Resistor Current Source

The quality of the constant current source created by R_S is determined by the temperature coefficient of the two resistors in series ($R_S + R_B$).

If the resistor value $R_S \gg R_B$ then the TCR is very good, but the signal from the sensor is proportionally very small. If the resistor value $R_B \gg R_S$, then the signal is good but the span TC is very poor (~ -2200 ppm/ $^{\circ}\text{C}$). The following equations or Graph I, can be used to determine the value of R_S which will provide the largest signal from the sensor, while still providing adequate span TC compensation. The key equations associated with the circuit shown in Figure II are:

$$(a) V_B = V_S \cdot \frac{R_B}{R_S + R_B}$$

$$(b) \frac{\dot{V}_B}{V_B} = \frac{\dot{R}_B}{R_B} - \frac{\dot{R}_S}{R_S} \times \left(\frac{1 - R_B}{R_S + R_B} \right)$$

$$(c) \dot{SC} = \dot{S} + \dot{V}_B$$

where SC is the compensated span

Solving for (b) we find that the ratio of R_B to R_S for the SCC family of pressure sensors is:

$$\frac{R_B}{R_S} = \frac{\dot{R}_B - \dot{R}_S}{\dot{S}_C - \dot{S}_U} \quad \text{where SC is the compensated span}$$

SU is the uncompensated span

For example, assume that the span must be within 1% of the calibrated value (25°C), and that the temperature is limited to $25^{\circ}\text{C} \pm 10^{\circ}\text{C}$. Also, assume the worst case die parameters of $\text{TCR} = 2200$ ppm/ $^{\circ}\text{C}$, $\text{TCS} = 2300$ ppm/ $^{\circ}\text{C}$ and that the series resistor has a worst case temperature coefficient $R_S/R_S = +100$ ppm/ $^{\circ}\text{C}$. The allowable TC error will be:

$$\frac{\dot{S}_C}{S_C} = \frac{1\% \text{ error}}{10^{\circ}\text{C}} = -1000 \text{ ppm}/^{\circ}\text{C}$$

By knowing the compensated span TC desired, we can now solve for the ratio of R_B to R_S .

$$\frac{R_B}{R_S} = \frac{2200 - 100}{-1000 - (-2300)} - 1 = 0.5$$

Therefore, if we assume that $R_B = 6.0\text{k}$ then $R_S = 12\text{k}$, the span TC error is less than 1% for all variations of die parameters. This simple configuration, shown in Figure III is only recommended when low cost is required and performance over temperature is not critical.

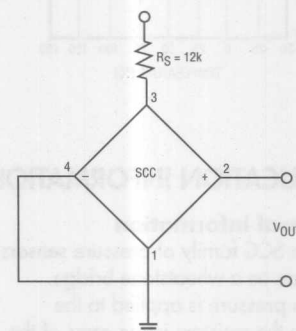
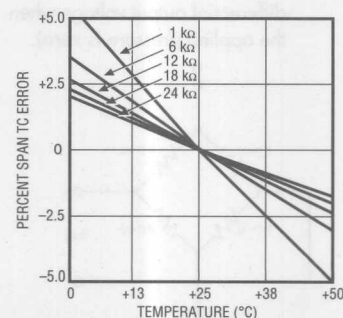


Figure III: Single Resistor Current Source

As shown in Graph I, different values of R_S result in varying degrees of span TC accuracy over the temperature ranges of 0°C – 50°C . The values in Graph I were calculated using the worst case die parameters as given in the above example. The values in the table also take into account the errors in span TC over temperature which will occur even if a perfect current source could be constructed.



Graph I

APPLICATION INFORMATION

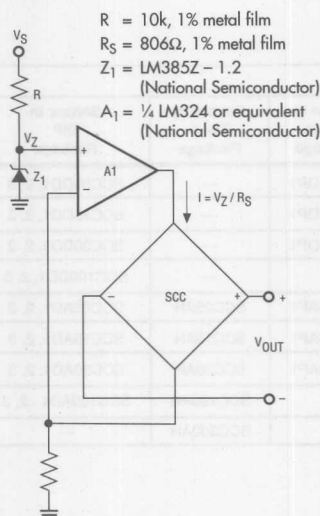


Figure IV: Single Op-Amp Current Source

One Op-Amp Constant Current Source

Typically, the most common way of generating a low cost constant current source is the single op-amp design as shown in Figure IV.

Here, the current thru the sensor is equal to the voltage at the non-inverting terminal divided by the resistor, R. The accuracy of this current source will vary given the accuracy of the op-amp, and grade of resistor values used around the sensor. However, current variations over the temperature range of 0°C - 50°C for this current source should be less than 0.5% of the full-scale current.

This scheme is probably the most commonly used as it provides reasonable accuracy with low cost and it is simple to manufacture. In using this technique with the SCC devices, we

recommend a 1.2V zener such as the LM358Z - 1.2 along with an 806 1% metal film resistor.

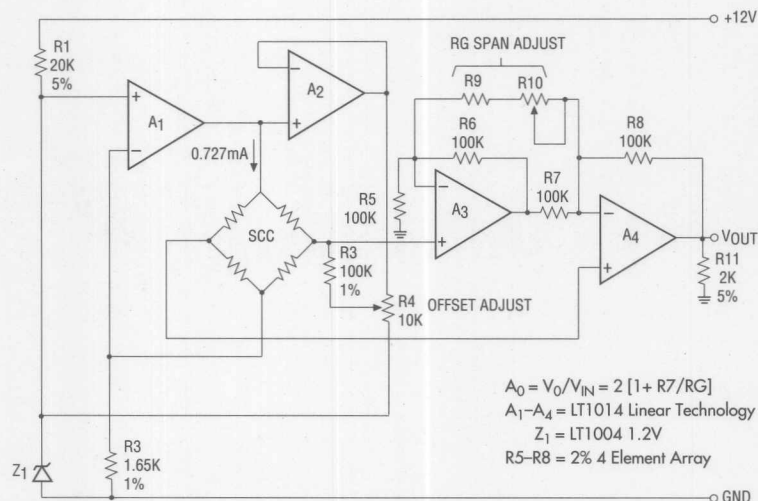
Amplifier Design

There are hundreds of instrumentation amplifier designs, and the intent here will be to briefly describe one circuit which:

- does not load the bridge
- involves minimal components
- provides maximum performance at the lowest cost

The choice of the operational amplifiers to use is based on individual cost/performance trade-offs. The accuracy will be primarily limited by offset voltage drift with temperature and noise performance.

A popular amplifier configuration which provides a 1 to 6 volt output is shown in Figure V below.



AMPLIFIER ADJUSTMENT PROCEDURE:

1. At reference pressure (0 psi for diff, and gage) adjust R4 until the output reads 0.050 volts.
2. With full pressure applied adjust R10 (span adjust) until V_{OUT} reads 5.0V.
3. Repeat steps 1 and 2 i

Sensor	Gain	R9	R10(POT)
SCC05D	106-275	500Ω	2K
SCC15D	72-172	1K	2K
SCC30D	46-115	1.5K	5K
SCC100D	30-81	2.26K	5K
SCC300D	57-137	1K	5K

Figure V

ORDERING INFORMATION

To order, use the following part numbers:

Pressure Range	Order Part Number						
	Sensor in Button Package	Sensor in "N" Package	Sensor in TO Package (Open Bridge)	Sensor in ½ "N" Package	Sensor in Nipple Package	Sensor in TO-5 Package	Sensor in DIP Package
0 to 5 psid or psig	SCC05D	SCC05DN	SCC05GSO	SCC05DN2	SCC05DP1	—	SCC05DD1, 2, 3
0 to 15 psid or psig	SCC15D	SCC15DN	SCC15GSO	SCC15DN2	SCC15DP1	—	SCC15DD1, 2, 3
0 to 30 psid or psig	SCC30D	SCC30DN	SCC30GSO	SCC30DN2	SCC30DP1	—	SCC30DD1, 2, 3
0 to 100 psig	SCC100D	SCC100DN	—	—	—	—	SCC100DD1, 2, 3
0 to 5 psia	SCC05A	SCC05AN	SCC05AHO	SCC05AN2	SCC05AP1	SCC05AH	SCC05AD1, 2, 3
0 to 15 psia	SCC15A	SCC15AN	SCC15AHO	SCC15AN2	SCC15AP1	SCC15AH	SCC15AD1, 2, 3
0 to 30 psia	SCC30A	SCC30AN	SCC30AHO	SCC30DN2	SCC30AP1	SCC30AH	SCC30AD1, 2, 3
0 to 100 psia	SCC100A	SCC100AN	SCC100AHO	—	—	SCC100AH	SCC100AD1, 2, 3
0 to 300 psia	—	—	SCC300AHO	—	—	SCC300AH	—

See Section 9 for Package Styles and Dimensions

SenSym

SX01, SX05 0 to 1 psi and 0 to 5 psi

PRESSURE SENSORS

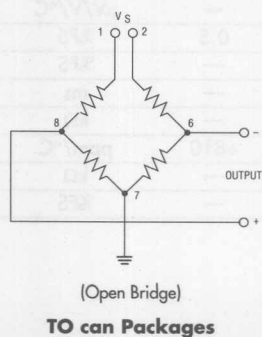
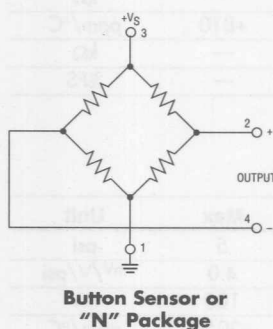
FEATURES

- Accurate Low Pressure Readings
- Low Cost
- High Impedance Bridge
- Low Noise

APPLICATIONS

- Medical Instrumentation
- Portable and Battery Powered Equipment
- Industrial Controls

EQUIVALENT CIRCUITS



GENERAL DESCRIPTION

The SX Series of pressure sensors provide the lowest cost components for measuring low pressures. These low pressure range devices were specifically designed to accurately measure differential, and gage, pressures of 0 to 1 psi (SX01) and 0 to 5 psi (SX05). They are meant for use with non-corrosive and non-ionic media, such as air, dry gases and the like.

The differential devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

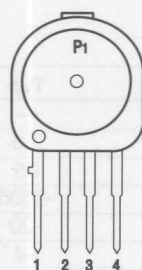
This product is packaged either in SenSym's standard low cost chip carrier "button" package, a plastic ported "N" package or a metal TO can package. All

packages are designed for applications where the sensing element is to be integral to the OEM equipment. These packages can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting. A closed bridge four-pin SIP configuration is provided for electrical connection to the button or "N" package. The TO can offers a 5-pin open bridge configuration.

Because of its high-impedance bridge, the SX Series is ideal for portable and low power or battery operated systems. Due to its low noise, the SX will also be found to be an excellent choice for medical and other low pressure measurements.

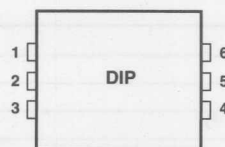
For further technical information, please contact your local SenSym office or the factory.

ELECTRICAL CONNECTIONS



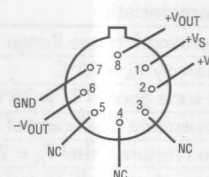
- | | |
|-----------|------------|
| 1) GROUND | 2) +OUTPUT |
| 3) +Vs | 4) -OUTPUT |

Button Sensor



- | | |
|----------------------|---------------|
| 1) -V _{OUT} | 2) GROUND |
| 3) +V _{OUT} | 4) No Connect |
| 5) +V _S | 6) No Connect |

DIP



Bottom View
(Open Bridge)

TO can Pinout

NOTE: Polarity applies for positive pressure applied to the high pressure port, P₁.
TO Package only available in an Open Bridge configuration. See SCC "ISO" series for application information.

PRESSURE SENSOR CHARACTERISTICS

Maximum Ratings (For All Devices)

Supply Voltage, V_S	+12V _{DC}
Temperature Ranges	
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Common-Mode Pressure	150 psig
Lead Temperature (soldering 10 sec)	300°C
Maximum Pressure ⁽¹⁰⁾	
SX01	20 psi
SX05	20 psi

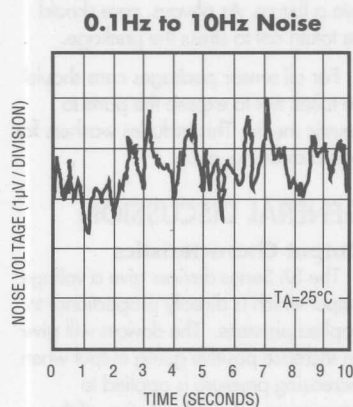
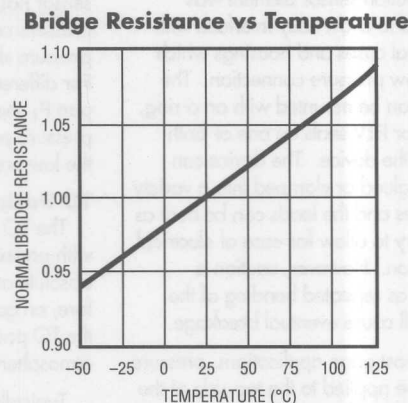
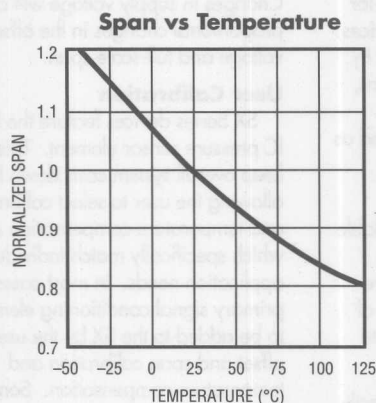
SX01 PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	1	psi
Sensitivity $T_A = 25^\circ\text{C}$	3.0	4.0	5.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	15	20	25	mV
Temperature Coefficient of Span ^(6, 9)	-2550	-2300	-2050	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+690	+750	+810	ppm/°C
Output Impedance	—	4.65	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SX05 PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	5	psi
Sensitivity $T_A = 25^\circ\text{C}$	2.0	3.0	4.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	50	75	100	mV
Temperature Coefficient of Span ^(6, 9)	-2550	-2300	-2050	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+690	+750	+810	ppm/°C
Output Impedance	—	4.65	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

TYPICAL PERFORMANCE CHARACTERISTICS

**SPECIFICATION NOTES:** (For All Devices)

- Note 1: Reference Conditions: Supply Voltage, V_S , = 5V_{DC}, T_A = 0°C to 70°C, Common-mode Line Pressure = 0 psig, Pressure Applied to P_1 , unless otherwise noted.
- Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.
- Note 3: See Definition of Terms.
Hysteresis - the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
- Note 4: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +70°C after:
a) 100 temperature cycles, 0°C to +70°C
b) 1.0 million pressure cycles, 0 psi to full-scale span.
- Note 5: Slope of the best straight line from 0°C to +70°C.
- Note 6: This is the best straight line fit for operation between 0°C and 70°C. For operation outside this temperature, contact factory for more specific applications information.
- Note 7: Response time for a 0 psi to full-scale span pressure step change.
- Note 8: Long term stability over a one year period.
- Note 9: This parameter is not 100% tested. It is guaranteed by process design and tested on a sample basis only.
- Note 10: If the maximum pressure is exceeded, even momentarily, the package may leak or burst, or the pressure sensing die may fracture.

MECHANICAL AND MOUNTING CONSIDERATIONS

Button Sensor Element

The button sensor element was designed to allow easy interface with additional cases and housings which then allow pressure connection. The device can be mounted with an o-ring, gasket, or RTV seals on one or both sides of the device. The device can then be glued or clamped into a variety of fixtures and the leads can be bent as necessary to allow for ease of electrical connection. However, caution is advised as repeated bending of the leads will cause eventual breakage.

For most gage applications, pressure should be applied to the top side of the device. (See Physical Construction Drawing.) For differential applications, the top side of the device (P_1) should be used as the high pressure port and the bottom (P_2) as the low pressure port.

The button SX package has a very small internal volume of 0.06 cubic centimeters for P_1 and 0.001 cubic centimeters for P_2 .

"N" Packaged Sensor

The "N" packaged sensor is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

The "N" package version of the sensor has two (2) tubes available for pressure connection. For gage devices, pressure should be applied to port P_1 . For differential pressure applications, port P_1 should be used as the high pressure port and P_2 should be used as the low pressure port.

TO Package

The TO package parts are available with pressure access only to P_1 for absolute and gauge pressure. Therefore, on gauge devices the bottom of the TO package must be left open to atmosphere.

Typically, tubing is attached directly around the top of the TO can or the package can be glued or o-ring sealed into a fixture. As always, care should be taken not to stress the package.

For all sensor packages care should be taken not to expose the parts to caustic media. This includes washers for board cleaning, etc..

are ratiometric to the supply voltage. Changes in supply voltage will cause proportional changes in the offset voltage and full-scale span.

User Calibration

SX Series devices feature the basic IC pressure sensor element. This will keep overall system costs down by allowing the user to select calibration and temperature compensation circuits which specifically match individual application needs. In most cases, the primary signal conditioning elements to be added to the SX by the user are: offset and span calibration and temperature compensation. Some typical circuits are shown in the application section.

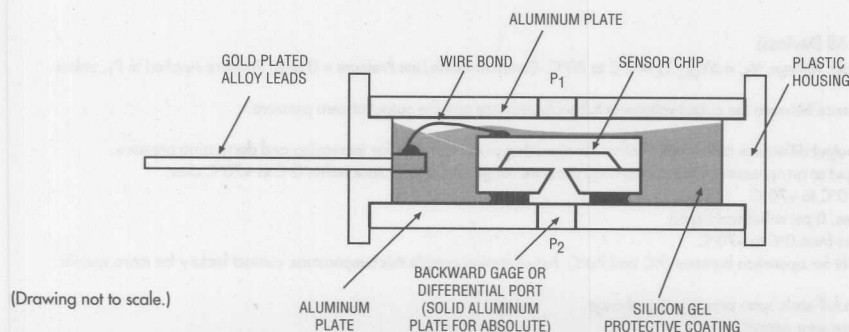
Media Compatibility

SX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective silicon gel (parylene coating for all TO can devices), some otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below for the basic sensor element and "N" Package, fluids must generally be compatible with silicon gel, RTV, plastic, and aluminum for forward gage use and RTV, silicon, glass and aluminum for backward gage or differential applications. For questions concerning media compatibility, contact the factory.

GENERAL DISCUSSION

Output Characteristics

The SX Series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increase positive going output when increasing pressure is applied to pressure port P_1 of the device. If the devices are operated in the backward gage mode, the output will increase with decreases in pressure. The devices



Physical Construction — Button Sensor Package

APPLICATION INFORMATION

General

The SX family of pressure sensors functions as a Wheatstone bridge. When pressure is applied to the device (see Figure 1) the resistors in the arms of the bridge change by an amount, Δ .

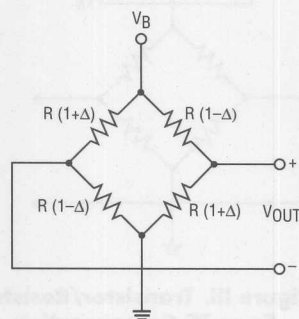


Figure 1. Button Sensor Bridge Schematic

The resulting differential output voltage V_O is easily shown to be $V_O = V_B \times \Delta$. Since the change in resistance is directly proportional to pressure, V_O can be written as:

$$V_O = S \times P \times V_B \pm V_{OS} \quad (1)$$

Where: V_O is the output voltage in mV
 S is the sensitivity in mV/V per psi
 P is the pressure in psi
 V_B is the bridge voltage in volts.

V_{OS} is the offset error (the differential output voltage when the applied pressure is zero). The offset voltage presents little problem in most applications, since it can easily be corrected for in the amplifier circuitry, or corrected digitally if a microprocessor is used in the system.

Temperature Effects

In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a dot (•) over the variable. For example,

$$\dot{S} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{\partial S}{\partial T}$$

From equation (1), and ignoring the V_{OS} term, it is seen that for a given

constant pressure, the output voltage change, as a function of temperature*, is:

$$\dot{V}_O = \dot{S} P V_B \quad (2)$$

Thus, in order for output voltage to be independent of temperature, the voltage across the bridge, V_B , must change with temperature in the "opposite direction" from the sensitivity change with temperature. From the typical curves for the temperature dependence of span ($\text{span} = S \times P \times V_B$), it can be seen that the sensitivity change with temperature is slightly non-linear and can be correlated very well with an equation of the form:

$$S = S_O [(1 - \beta T_D) + \rho T_D^2] \quad (3)$$

where T_D is the temperature difference between 25°C and the temperature of interest, S_O is the sensitivity at 25°C, and beta (β) and rho (ρ) are correlation constants. Fortunately, between 0°C and 70°C the change in sensitivity with temperature is quite linear, and excellent results can be obtained over this temperature range by ignoring the second-order temperature dependent term. Operating outside the 0°C and 70°C temperature range will require a more rigorous mathematical approach and the use of non-linear compensating circuitry, if accuracy of better than $\pm 1\%$ is required. Because the majority of SX applications fall within the 0°C to 70°C operating temperature range, the discussion and circuit designs given here will ignore the non-linear effects. Thus:

$$S = S_O (1 - \beta T_D) \quad (4)$$

Substituting equation (4) into equation (1), and ignoring V_{OS} , it can be shown that the necessary bridge voltage, V_B , will be of the form:

$$V_B = \frac{V_{BO}}{(1 - \beta T_D)} = V_{BO} [(1 + \beta T_D + (\beta T_D)^2 + \dots)]$$

where V_{BO} is the bridge voltage at 25°C.

This equation is again non-linear. However, for the temperature range of interest, and since β is small (0.230%/°C from the electrical tables), the above expression can be approximated by:

$$V_B = V_{BO} [1 + \beta T_D]$$

with less than 1% error. Thus to compensate for a negative 2300 ppm/°C sensitivity change with temperature, the bridge voltage should increase with temperature at a rate of +2300 ppm/°C.

The above value of bridge voltage change will be used in the circuit discussions that follow. That is to say, the required change in terms of ppm/°C is:

$$\left(\frac{\dot{V}_B}{V_B} \right) = +2300 \text{ ppm/}^\circ\text{C.}$$

The bridge input resistance*, R_B , also changes with temperature and is quite linear in the temperature range of interest. The bridge resistance has a temperature co-efficient of typically:

$$\left(\frac{\dot{R}_B}{R_B} \right) = +750 \text{ ppm/}^\circ\text{C.}$$

This term enters into several compensation circuit equations, particularly when the bridge excitation is from a constant current source.

To summarize, the following list indicates how the sensor variables can be accommodated:

- Full-scale span from device to device. Make the gain adjustment in the op amp circuitry
- Temperature coefficient of span:
 - 1) temperature compensate the bridge or
 - 2) temperature compensate the op amp gain
- Offset voltage: Adjustment in op amp circuitry

Note: Application information shown here is based as the closed bridge configuration, see the SCC "ISO" Series datasheet.

APPLICATION INFORMATION (Continued)

- Offset voltage temperature coefficient:
Usually can be ignored. For more precise design requirements, contact the factory for information on how to compensate for this term.

Bridge Compensation Circuits

Although thermistors can be used to temperature compensate the bridge (and in fact will be required for extended temperature operation), they are inherently non-linear, difficult to use in volume production, and more expensive than the circuit approaches shown here, which use inexpensive semiconductor devices. The circuits shown have been designed to incorporate a minimum number of adjustments and allow inter-changeability of devices with little variation from device to device.

In general, equations for the bridge voltage and its change with temperature are given to enable the user to modify or adjust the circuitry as required.

1. Diode String (Figure II)

For systems using 6V supplies, this method of compensating for the effects of span over temperature is the lowest cost solution. The diodes are small signal silicon diodes, such as 1N914 or 1N4148, and do not have to be matched.

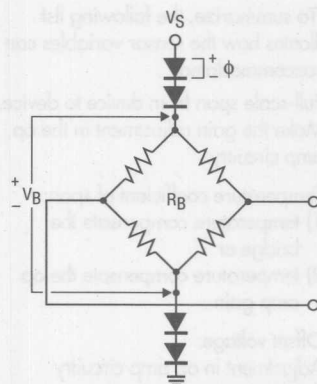


Figure II. Diode String Span Compensation

$$a) V_B = V_S - 4\phi$$

$$b) \left(\frac{\dot{V}_B}{V_B} \right) = \frac{-4 \left(\frac{\dot{\phi}}{\phi} \right)}{\left(\frac{V_S}{\phi} - 4 \right)}$$

$$c) \left(\frac{\dot{\phi}}{\phi} \right) \approx -2500 \text{ ppm}/^\circ\text{C} \text{ for silicon diodes}$$

Figure II. Equations

For example, solving equation (b) for V_B/V_S when

$$V_S = 6.0\text{V}$$

$$\phi = 0.7\text{V}$$

Yields:

$$\frac{\dot{V}_B}{V_B} = 2188 \text{ ppm}/^\circ\text{C}$$

Since the sensor's span changes with temperature at $-2300 \text{ ppm}/^\circ\text{C}$, this technique will typically result in an overall negative TC of $112 \text{ ppm}/^\circ\text{C}$. This error is acceptable in most applications.

For operation with V_S above 6V, it is recommended to use the transistor or constant current compensation technique.

2. Transistor Compensation Network

Figure III uses a single transistor to simulate a diode string, with the equations as shown. The values shown in Table I were found to give excellent results over 0°C to 70°C . Again, if precision temperature compensation is required for each device, the fixed value resistors shown for R_1 in Table I can be replaced by a 3.24k resistor in series with a 1k pot. Then, each device's temperature compensation can be individually adjusted.

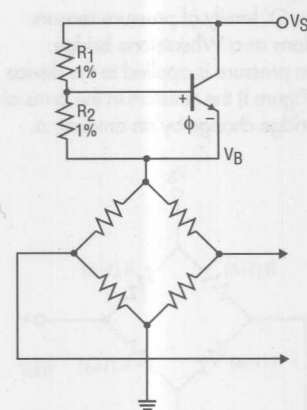


Figure III. Transistor/Resistor Span TC Compensation

$$a) V_B = V_S - \alpha \phi$$

$$b) \left(\frac{\dot{V}_B}{V_B} \right) = - \left(\frac{\dot{\phi}}{\phi} \right) \left(\frac{\alpha}{V_S - \alpha} \right)$$

$$c) \alpha = 1 + \frac{R_1}{R_2}$$

$$d) \left(\frac{\dot{\phi}}{\phi} \right) \approx -2500 \text{ ppm}/^\circ\text{C}$$

Table I. Selected R Values vs V_S for Figure III

V_S	$R_1(\Omega)$	$R_2(\Omega)$
5V	3.32k	1.37k
9V	4.02k	787
12V	4.22k	590

3. Constant Current Excitation (Figure IV)

The circuits shown in Figures II and III, although simple and inexpensive, have one drawback in that the voltage across the bridge is determined by the compensation network. That is, the compensation network is determined and what voltage is "leftover" is across the bridge. The circuit of Figure IV solves this problem and allows the bridge voltage to be independently

APPLICATION INFORMATION (Continued)

selected. In Figure IV, the bridge is driven from a constant current source, the LM334, which has a very well known and repeatable temperature coefficient of +3360 ppm/°C. This temperature coefficient (TC), in conjunction with the TC of the bridge resistance, is too high to compensate the sensitivity TC, hence resistor R_2 is added to reduce the total circuit TC.

The basic design steps for this method of temperature compensation are shown below. However, please refer to SenSym's Application Note SSAN-16 for details on the temperature compensation technique.

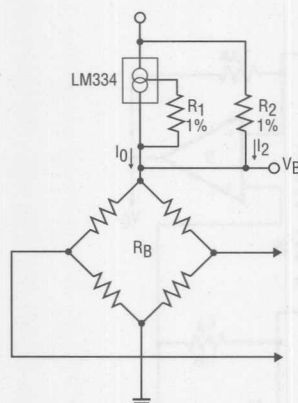


Figure IV. Constant Current Span TC Compensation

$$a) V_B = \alpha (V_S + I_O R_2)$$

$$b) \left(\frac{V_B}{V_S} \right) = \left(\frac{R_B}{R_1} \right) (1 - \alpha) + \left(\frac{I_O}{V_S} \right) \left[1 - \alpha \left(\frac{V_S}{V_B} \right) \right]$$

$$c) \alpha = \frac{R_B}{R_2 + R_B}$$

$$d) \left(\frac{I_O}{V_S} \right) = 3360 \text{ ppm/}^\circ\text{C}, \left(\frac{R_B}{R_1} \right) = +750 \text{ ppm/}^\circ\text{C}$$

$$e) I_O = \frac{67.7 \text{ mV}}{R_1}$$

The design steps are straightforward:

- 1) Knowing V_S and the desired bridge voltage V_B , solve equation (b) for α .
- 2) Now, solve equation (c) for R_2 , letting $R_B = 4650\Omega$.
- 3) Solve equation (a) for I_O .
- 4) Find R_1 , or its nearest 1% tolerance value from equation (e).

Table II gives specific 1% resistor values in ohms, for several popular system voltages. For best results, the resistors should be 1% metal film with a low temperature coefficient.

Table II. Selected R Values vs V_S for Figure IV

V_S	V_B	$R_1(\Omega)$	$R_2(\Omega)$
5V	3V	137	12.7k
6V	4V	100	11.3k
9V	6V	66.5	11.3k
12V	9V	41.2	9.76k
15V	10V	40.2	11.3k

Table III. For 0 to 70°C Operation

V_S	V_B	R_2	R_1	FS SPAN	R_S	R_P
5V	3.5V	10.5k	110 Ω	3V	604 Ω	2k
6V	4.5V	9.76k	82.5 Ω	4V	604 Ω	2k
9V	7V	9.25k	52.3 Ω	5V	1k	2k
12V	10V	8.45k	35.7 Ω	5V	1.82k	5k
12V	10V	8.45k	35.7 Ω	10V	511 Ω	2k
15V	12V	8.87k	30.1 Ω	5V	1.4k	5k
15V	12V	8.87k	30.1 Ω	10V	604 Ω	2k

Amplifier Design

There are hundreds of instrumentation amplifier designs, and the intent here will be to briefly describe one circuit which:

- does not load the bridge
- involves minimal components
- provides excellent performance

The choice of the operational amplifiers to use is based on individual cost/performance trade-offs. The accuracy will be primarily limited by the amplifier's common-mode rejection, offset voltage drift with temperature and noise performance. Low cost, low performance devices, such as the LM324 can be used if the temperature range is limited to $25^\circ\text{C} \pm 15^\circ\text{C}$ and an accuracy of $\pm 2\%$ is adequate. For more precise applications, amplifiers such as the LT1014 and LT1002 have been found to be excellent.

An amplifier that uses a single supply is shown in Figure V. Table III gives resistor values for various supply and full-scale output combinations. Details of this basic amplifier are shown in SenSym Application Note #17 (SSAN-17).

APPLICATION INFORMATION (Continued)

Amplifier Adjustment Procedure

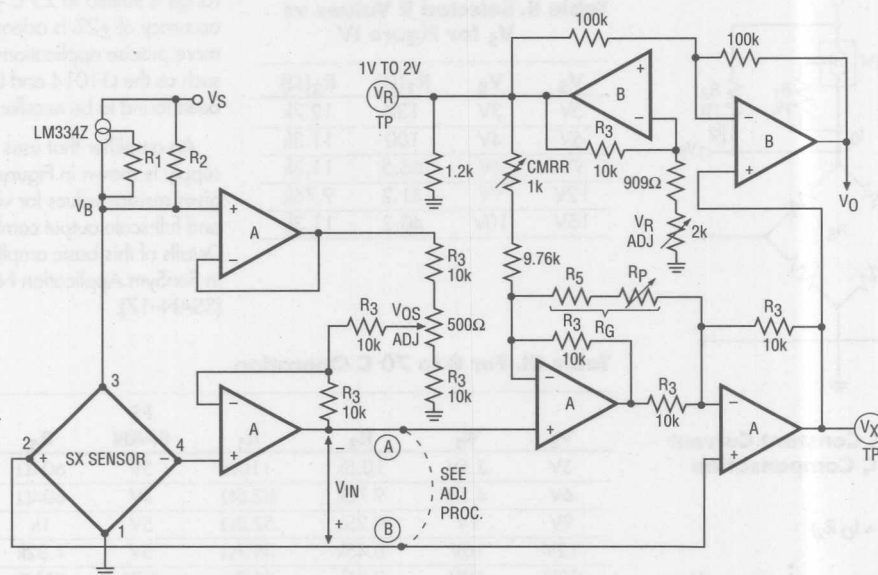
1. Without pressure applied,
 - (a) Short points A and B together as shown in Figure V. Adjust the 1k common-mode rejection (CMRR) pot until the voltage at test point (TP) V_X is equal to the voltage at test point (TP) V_R . This is easily accomplished by placing a digital voltmeter between these test points and adjusting for 0.000.

- (b) Remove the short and adjust the 500Ω offset adjust pot until V_X is again equal to V_R .
 - (c) Adjust the 2k reference (V_R) adjust pot to get an output voltage (V_O) equal to 1.00 V.

2. Apply the full-scale pressure and adjust the span adjust pot, R_5 , to get the output voltage that is desired to represent full-scale.

Factory Compensated Devices

This application note provides the necessary information for temperature compensating and calibrating the SX sensors. In some cases, the customer may find that SX devices which have been factory adjusted for temperature compensation and span are more economical for a particular application. SenSym does offer devices with this feature. For more information on these factory calibrated and compensated devices, the SCX Series, please contact your nearest SenSym sales office or the SenSym factory.



A LT1014CN
B LM10CN

$$V_O = 4 \left[1 + \frac{10k}{R_G} \right] V_{IN} + V_R$$

Resistors Labeled R_3 , Are An 8-Element Resistor Array, 10kΩ

Figure V. Button Sensor Amplifier Circuit

A/D CONVERTER

The circuit shown in Figure VI, is an example of a circuit that provides an 8-bit parallel output for a 0-1 psig input pressure. This design can be easily adapted to other pressure ranges and/or a serial data output.

Circuit Description

The LM334 network at the top of the SX sensor bridge provides the span temperature compensation. (See SenSym's Application Note SSAN-16 for details.)

The bridge voltage, V_{IN} is impressed across R_1 by buffer amplifiers A_1 and A_2 as shown. The resultant current flows thru R_2 to provide a differential output voltage V_O which is the input to the A/D converter.

$$V_O = V_{IN} \left(\frac{R_2}{R_1} \right)$$

Because the offset voltage of the bridge is always negative, it will cause an error current thru R_1 which is always into the inverting input of amplifier A_4 . Resistor network R_3 is used to remove this error current (shunt it to ground) so that it does not flow thru R_2 to the output.

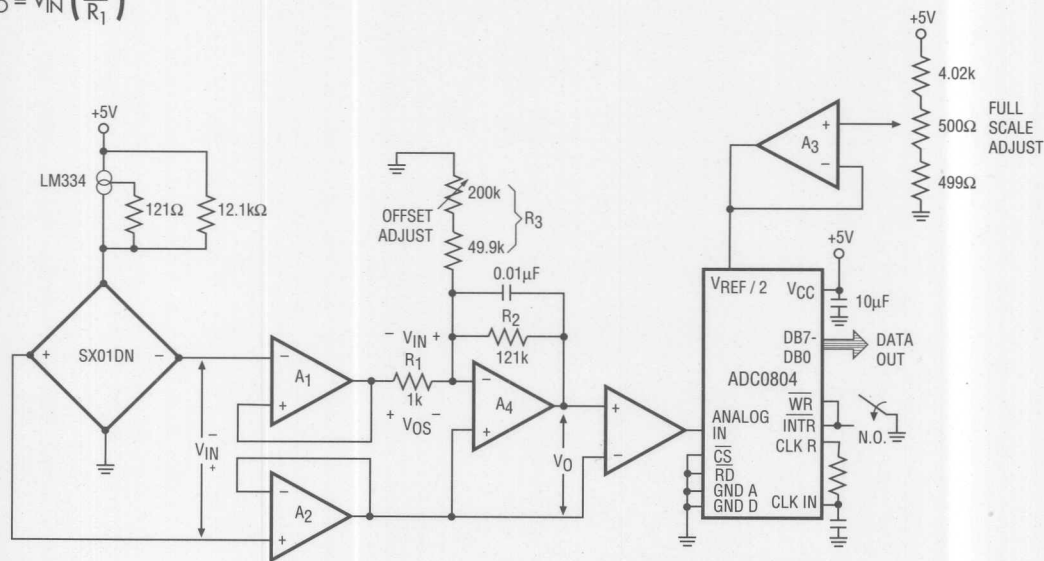
Amplifier A_3 provides a buffered reference to the A/D to adjust the full-scale span.

The A/D is connected such that the completion of one conversion automatically begins the next conversion. See National Semiconductor ADC0804 data sheet for other applications and configurations.

Adjustment Procedure

1. Without pressure applied, adjust the offset adjust pot until the digital output gives all zero's with the LSB flickering between one and zero.
2. Apply 1 psig (full-scale pressure) and adjust the full-scale adjust pot until the output code is all ones. Again, the LSB should be flickering between one and zero.

1



LM334, National Semiconductor Corp.
 Amplifier A: LT1014 (N) (Quad), Linear Technology Inc.
 A/D: ADC0804, National Semiconductor Corp.
 All Resistors 1% Metal Film.
 All Pots Cermet 10-Turn.

Figure VI. 0 to 1 psig Input, 8-Bit Parallel Output

ORDERING INFORMATION

To order, use the following part numbers:

Pressure Range	Order Part Number					
	Sensor in Button Package	Sensor in "N" Package	Sensor in TO Package (Open Bridge)	Sensor in ½ "N" Package	Sensor in Nipple Package	Sensor in DIP Package
0 to 1 psid or psig	SX01D	SX01DN	SX01GSO	SX01DN2	SX01DP1	SX01DD1, 2, 3
0 to 5 psid or psig	SX05D	SX05DN	SX05GSO	SX05DN2	SX05DP1	SX05DD1, 2, 3
0 to 5 psia	SX05A	SX05AN	SX05AHO	SX05AN2	SX05AP1	SX05AD1, 2, 3

See Section 9 for Package Styles and Dimensions

1536 7100

SenSym SX15, SX30, SX100, SX150

0 to 15 psi and 0 to 150 psi

PRESSURE SENSORS

1

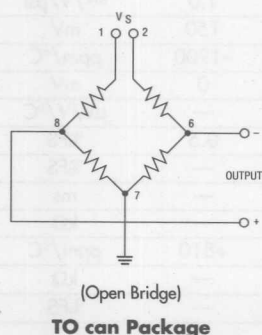
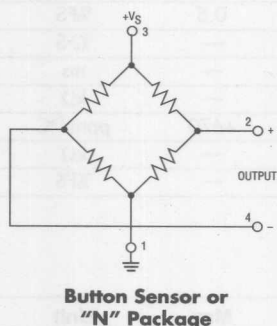
FEATURES

- High Impedance Bridge
- Absolute and Differential (Gage) Devices
- Low Power Consumption for Battery Operation

APPLICATIONS

- Industrial Controls
- Pneumatic Controls
- Medical Instrumentation
- Barometry

EQUIVALENT CIRCUITS



GENERAL DESCRIPTION

The SX Series of pressure sensors provide the most cost effective method of measuring pressures up to 150 psi. These sensors were specifically designed to be used with non-corrosive and non-ionic media, such as air, dry gases and the like. Convenient pressure ranges are available to measure differential, gage, and absolute pressures from 0 to 15 psi (SX15) up to 0 to 150 psi (SX150).

The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

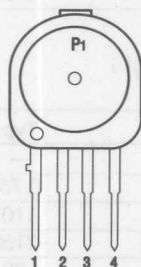
This product is packaged either in SenSym's standard low cost chip carrier "button" package, a plastic ported "N" package or a metal TO can package. Both

packages are designed for applications where the sensing element is to be integral to the OEM equipment. These packages can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting. A closed bridge four-pin SIP configuration is provided for electrical connection to the button and "N" package. The TO can offers a 5-pin open bridge configuration.

Because of its high-impedance bridge, the SX Series is also ideal for portable and low power or battery operated systems. Due to its low noise, the SX will be found to be an excellent choice for medical and low pressure measurements.

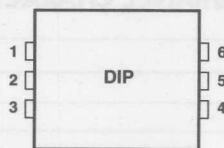
For further technical information please contact your local SenSym office or the factory.

ELECTRICAL CONNECTIONS



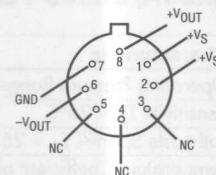
- 1) GROUND 2) +OUTPUT
3) +Vs 4) -OUTPUT

Button Sensor



- 1) -V_{OUT} 2) GROUND
3) +V_{OUT} 4) No Connect
5) +Vs 6) No Connect

DIP



Bottom View
(Open Bridge)

TO can Pinout

NOTE: Polarity applies for positive pressure applied to the high pressure port, P₁.
TO Package only available in an Open Bridge configuration. See SCC "ISO" series for application information.

PRESSURE SENSOR CHARACTERISTICS

Maximum Ratings (For All Devices)

Supply Voltage, V_S	+12V _{DC}
Temperature Ranges	
Operating	-40°C to +85°C
Storage	-55°C to +125°C
Maximum Pressure at any Port ⁽¹¹⁾	150 psig
Lead Temperature (soldering 10 sec)	300°C
Maximum Pressure ⁽¹⁰⁾	
SX15	30 psi
SX30	60 psi
SX100	150 psi
SX150	200 psi

SX15A/SX15D PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	15	psi
Sensitivity $T_A = 25^\circ\text{C}$	1.0	1.5	2.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+590	+630	+670	ppm/°C
Output Impedance	—	4.5	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SX30A/SX30D PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	30	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.5	0.75	1.0	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/°C
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(6, 9)	+690	+750	+810	ppm/°C
Output Impedance	—	4.5	—	kΩ
Repeatability ⁽⁴⁾	—	0.5	—	%FS

SX100A/SX100D PERFORMANCE CHARACTERISTICS⁽¹⁾

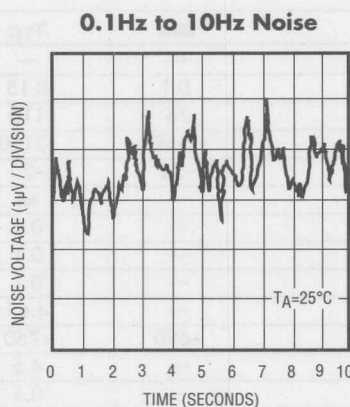
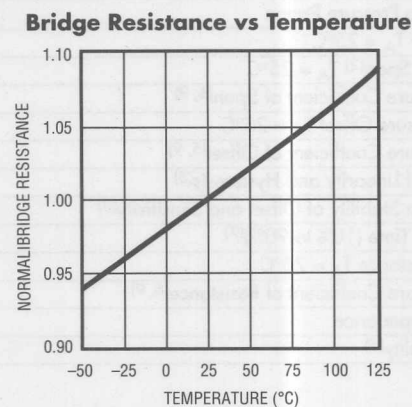
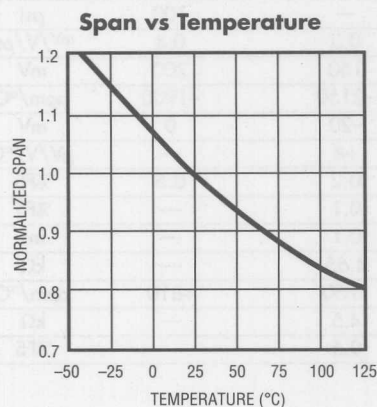
Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	100	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.2	0.3	0.4	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	100	150	200	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/ $^\circ\text{C}$
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	$\mu\text{V/V}/^\circ\text{C}$
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	k Ω
Temperature Coefficient of Resistance ^(6, 9)	+690	+750	+810	ppm/ $^\circ\text{C}$
Output Impedance	—	4.5	—	k Ω
Repeatability ⁽⁴⁾	—	0.5	—	%FS

1

SX150A/SX150D PERFORMANCE CHARACTERISTICS⁽¹⁾

Characteristic	Min	Typ	Max	Unit
Operating Pressure Range	—	—	150	psi
Sensitivity $T_A = 25^\circ\text{C}$	0.1	0.15	0.2	mV/V/psi
Full-scale Span ⁽²⁾ $T_A = 25^\circ\text{C}$	75	110	150	mV
Temperature Coefficient of Span ^(6, 9)	-2400	-2150	-1900	ppm/ $^\circ\text{C}$
Zero Pressure Offset $T_A = 25^\circ\text{C}$	-35	-20	0	mV
Temperature Coefficient of Offset ^(5, 9)	—	+4	—	$\mu\text{V/V}/^\circ\text{C}$
Combined Linearity and Hysteresis ⁽³⁾	—	0.2	0.5	%FS
Long Term Stability of Offset and Sensitivity ⁽⁸⁾	—	0.1	—	%FS
Response Time (10% to 90%) ⁽⁷⁾	—	0.1	—	ms
Input Resistance $T_A = 25^\circ\text{C}$	—	4.65	—	k Ω
Temperature Coefficient of Resistance ^(6, 9)	+690	+750	+810	ppm/ $^\circ\text{C}$
Output Impedance	—	4.5	—	k Ω
Repeatability ⁽⁴⁾	—	0.5	—	%FS

TYPICAL PERFORMANCE CHARACTERISTICS

**SPECIFICATION NOTES:** (For All Devices)

- Note 1: Reference Conditions: Supply Voltage, V_S , = $5V_{DC}$, T_A = 0°C to 70°C , Common-mode Line Pressure = 0 psig, Pressure Applied to P_1 , unless otherwise noted.
- Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.
- Note 3: See Definition of Terms.
Hysteresis - the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
- Note 4: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to $+70^\circ\text{C}$ after:
a) 100 temperature cycles, 0°C to $+70^\circ\text{C}$
b) 1.0 million pressure cycles, 0 psi to full-scale span.
- Note 5: Slope of the best straight line from 0°C to $+70^\circ\text{C}$.
- Note 6: This is the best straight line fit for operation between 0°C and 70°C . For operation outside this temperature, contact factory for more specific applications information.
- Note 7: Response time for a 0 psi to full-scale span pressure step change.
- Note 8: Long term stability over a one year period.
- Note 9: This parameter is not 100% tested. It is guaranteed by process design and tested on a sample basis only.
- Note 10: If the maximum pressure is exceeded, even momentarily, the package may leak or burst, or the pressure sensing die may fracture.
- Note 11: Maximum pressure at any port is the maximum operating plus common-mode pressure which can be applied.

MECHANICAL AND MOUNTING CONSIDERATIONS

Button Sensor Element

The button sensor element was designed to allow easy interface with additional cases and housings which then allow pressure connection. The device can be mounted with an o-ring, gasket, or RTV seals on one or both sides of the device. The device can then be glued or clamped into a variety of fixtures and the leads can be bent as necessary to allow for ease of electrical connection. However, caution is advised as repeated bending of the leads will cause eventual breakage.

For most gage applications, pressure should be applied to the top side of the device. (See Physical Construction Drawing.) For differential applications, the top side of the device (P_1) should be used as the high pressure port and the bottom (P_2) as the low pressure port.

The button SX package has a very small internal volume of 0.06 cubic centimeters for P_1 and 0.001 cubic centimeters for P_2 .

"N" Packaged Sensor

The "N" packaged sensor is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

The "N" package version of the sensor has two (2) tubes available for pressure connection. For gage devices, pressure should be applied to port P_1 . For differential pressure applications, port P_1 should be used as the high pressure port and P_2 should be used as the low pressure port.

TO Package

The TO package parts are available with pressure access only to P_1 for absolute and gauge pressure. Therefore, on gauge devices the bottom of the TO package must be left open to atmosphere.

Typically, tubing is attached directly around the top of the TO can or the package can be glued or o-ring sealed into a fixture. As always, care should be taken not to stress the package.

For all sensor packages care should be taken not to expose the parts to caustic media. This includes washers for board cleaning, etc..

GENERAL DISCUSSION

Output Characteristics

The SX Series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increase positive going output when increasing pressure is applied to pressure port P_1 of the device. If the devices are operated in the backward gage mode, the output will increase

with decreases in pressure. The devices are ratiometric to the supply voltage. Changes in supply voltage will cause proportional changes in the offset voltage and full-scale span.

User Calibration

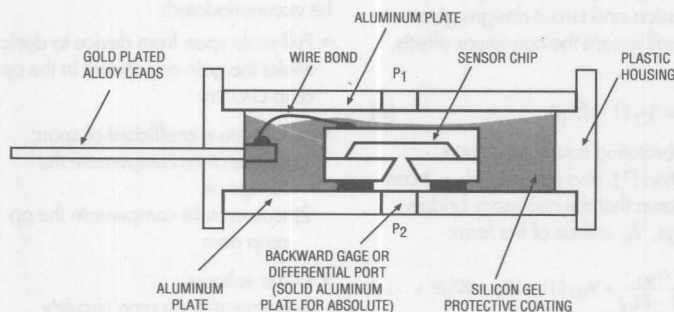
SX Series devices feature the button IC pressure sensor element. This will keep overall system costs down by allowing the user to select calibration and temperature compensation circuits which specifically match individual application needs. In most cases, the primary signal conditioning elements to be added to the SX by the user are: offset and span calibration and temperature compensation. Some typical circuits are shown in the application section.

Vacuum Reference (Absolute Devices)

Absolute sensors have a hermetically sealed vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

Media Compatibility

SX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective silicon gel (parylene coating for all TO can devices), some otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below for the button sensor element and "N" package, fluids must generally be compatible with silicon gel, RTV, plastic, and aluminum for forward gage use and RTV, silicon, glass and aluminum for backward gage or differential applications. For questions concerning media compatibility, contact the factory.



Physical Construction

(Drawing not to scale.)

APPLICATION INFORMATION

General

The SX family of pressure sensors functions as a Wheatstone bridge. When pressure is applied to the device (see Figure 1) the resistors in the arms of the bridge change by an amount, Δ .

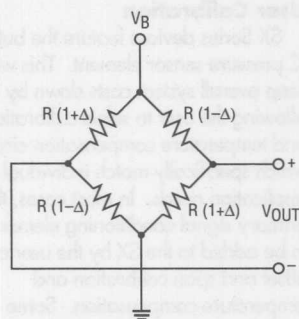


Figure 1. Button Sensor Bridge Schematic

The resulting differential output voltage V_O is easily shown to be $V_O = V_B \times \Delta$. Since the change in resistance is directly proportional to pressure, V_O , can be written as:

$$V_O = S \times P \times V_B \pm V_{OS} \quad (1)$$

Where: V_O is the output voltage in mV
 S is the sensitivity in mV/V per psi
 P is the pressure in psi
 V_B is the bridge voltage in volts.

V_{OS} is the offset error (the differential output voltage when the applied pressure is zero). The offset voltage presents little problem in most applications, since it can easily be corrected for in the amplifier circuitry, or corrected digitally if a microprocessor is used in the system.

Temperature Effects

In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a dot (•) over the variable. For example,

$$\dot{S} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{\partial S}{\partial T}$$

From equation (1), and ignoring the V_{OS} term, it is seen that for a given

constant pressure, the output voltage change, as a function of temperature*, is:

$$\dot{V}_O = \dot{S} P V_B \quad (2)$$

Thus, in order for output voltage to be independent of temperature, the voltage across the bridge, V_B , must change with temperature in the "opposite direction" from the sensitivity change with temperature. From the typical curves for the temperature dependence of span ($\text{span} = S \times P \times V_B$), it can be seen that the sensitivity change with temperature is slightly non-linear and can be correlated very well with an equation of the form:

$$S = S_O [(1 - \beta T_D) + \rho T_D^2] \quad (3)$$

where T_D is the temperature difference between 25°C and the temperature of interest, S_O is the sensitivity at 25°C, and beta (β) and rho (ρ) are correlation constants. Fortunately, between 0°C and 70°C the change in sensitivity with temperature is quite linear, and excellent results can be obtained over this temperature range by ignoring the second-order temperature dependent term. Operating outside the 0°C and 70°C temperature range will require a more rigorous mathematical approach and the use of non-linear compensating circuitry, if accuracy of better than $\pm 1\%$ is required. Because the majority of SX applications fall within the 0°C to 70°C operating temperature range, the discussion and circuit designs given here will ignore the non-linear effects. Thus:

$$S = S_O (1 - \beta T_D) \quad (4)$$

Substituting equation (4) into equation (1), and ignoring V_{OS} , it can be shown that the necessary bridge voltage, V_B , will be of the form:

$$V_B = \frac{V_{BO}}{(1 - \beta T_D)} = V_{BO} [(1 + \beta T_D + (\beta T_D)^2 + \dots)]$$

where V_{BO} is the bridge voltage at 25°C.

This equation is again non-linear. However, for the temperature range of interest, and since β is small (0.215%/°C from the electrical tables), the above expression can be approximated by:

$$V_B = V_{BO} [1 + \beta T_D]$$

with less than 1% error. Thus to compensate for a negative 2150 ppm/°C sensitivity change with temperature, the bridge voltage should increase with temperature at a rate of +2150 ppm/°C.

The above value of bridge voltage change will be used in the circuit discussions that follow. That is to say, the required change in terms of ppm/°C is:

$$\left(\frac{\dot{V}_B}{V_B} \right) = +2050 \text{ ppm/}^\circ\text{C}$$

The bridge input resistance*, R_B , also changes with temperature and is quite linear in the temperature range of interest. The bridge resistance has a temperature co-efficient of typically:

$$\left(\frac{\dot{R}_B}{R_B} \right) = +750 \text{ ppm/}^\circ\text{C}$$

This term enters into several compensation circuit equations, particularly when the bridge excitation is from a constant current source.

To summarize, the following list indicates how the sensor variables can be accommodated:

- Full-scale span from device to device. Make the gain adjustment in the op amp circuitry
- Temperature coefficient of span:
 - 1) temperature compensate the bridge or
 - 2) temperature compensate the op amp gain
- Offset voltage: Adjustment in op amp circuitry

Note: Application information shown here is based as the closed bridge configuration, see the SCC "ISO" Series datasheet.

APPLICATION INFORMATION (Continued)

- Offset voltage temperature coefficient:
Usually can be ignored. For more precise design requirements, contact the factory for information on how to compensate for this term.

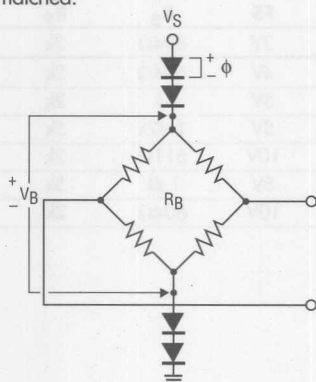
Bridge Compensation Circuits

Although thermistors can be used to temperature compensate the bridge (and in fact will be required for extended temperature operation), they are inherently non-linear, difficult to use in volume production, and more expensive than the circuit approaches shown here, which use inexpensive semiconductor devices. The circuits shown have been designed to incorporate a minimum number of adjustments and allow inter-changeability of devices with little variation from device to device.

In general, equations for the bridge voltage and its change with temperature are given to enable the user to modify or adjust the circuitry as required.

1. Diode String (Figure II)

For systems using 6V supplies, this method of compensating for the effects of span over temperature is the lowest cost solution. The diodes are small signal silicon diodes, such as 1N914 or 1N4148, and do not have to be matched.

**Figure II. Diode String Span Compensation**

$$a) V_B = V_S - 4\phi$$

$$b) \left(\frac{V_B}{V_S} \right) = \frac{-4 \left(\frac{\phi}{\phi} \right)}{\left(\frac{V_S}{V_S} - 4 \right)}$$

$$c) \left(\frac{\phi}{\phi} \right) \approx -2500 \text{ ppm}/^{\circ}\text{C} \text{ for silicon diodes}$$

Figure II. Equations

For example, solving equation (b) for V_B/V_S when

$$V_S = 6.0\text{V}$$

$$\phi = 0.7\text{V}$$

Yields:

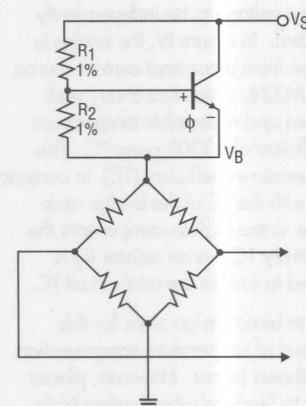
$$\frac{V_B}{V_S} = 2188 \text{ ppm}/^{\circ}\text{C}$$

Since the sensor's span changes with temperature at $-2150 \text{ ppm}/^{\circ}\text{C}$, this technique will typically result in an overall negative TC of $38 \text{ ppm}/^{\circ}\text{C}$. This error is acceptable in most applications.

For operation with V_S above 6V, it is recommended to use the transistor or constant current compensation technique.

2. Transistor Compensation Network

Figure III uses a single transistor to simulate a diode string, with the equations as shown. The values shown in Table I were found to give excellent results over 0°C to 70°C . Again, if precision temperature compensation is required for each device, the fixed value resistors shown for R_1 in Table I can be replaced by a 3.24k resistor in series with a 1k pot. Then, each device's temperature compensation can be individually adjusted.

**Figure III. Transistor/Resistor Span TC Compensation**

$$a) V_B = V_S - \alpha \phi$$

$$b) \left(\frac{V_B}{V_S} \right) = - \left(\frac{\phi}{\phi} \right) \left(\frac{\alpha}{V_S - \alpha} \right)$$

$$c) \alpha = 1 + \frac{R_1}{R_2}$$

$$d) \left(\frac{\phi}{\phi} \right) \approx -2500 \text{ ppm}/^{\circ}\text{C}$$

Table I. Selected R Values vs V_S for Figure III

V_S	$R_1(\Omega)$	$R_2(\Omega)$
5V	3.32k	1.43k
9V	4.02k	806
12V	4.22k	604

3. Constant Current Excitation (Figure IV)

The circuits shown in Figures II and III, although simple and inexpensive, have one drawback in that the voltage across the bridge is determined by the compensation network. That is, the compensation network is determined and what voltage is "leftover" is across the bridge. The circuit of Figure IV solves this problem and allows the

APPLICATION INFORMATION (Continued)

bridge voltage to be independently selected. In Figure IV, the bridge is driven from a constant current source, the LM334, which has a very well known and repeatable temperature coefficient of +3300 ppm/°C. This temperature coefficient (TC), in conjunction with the TC of the bridge resistance, is too high to compensate the sensitivity TC, hence resistor R_2 is added to reduce the total circuit TC.

The basic design steps for this method of temperature compensation are shown below. However, please refer to SenSym's Application Note SSAN-16 for details on the temperature compensation technique.

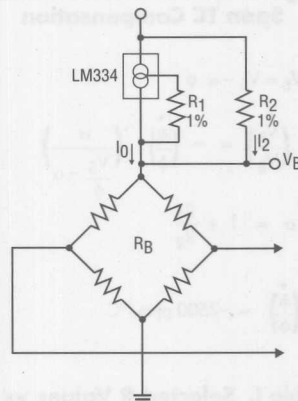


Figure IV. Constant Current Span TC Compensation

$$a) V_B = \alpha (V_S + I_O R_2)$$

$$b) \left(\frac{V_B}{V_S}\right) = \left(\frac{R_B}{R_2}\right)(1-\alpha) + \left(\frac{I_O}{I_S}\right)\left[1-\alpha\left(\frac{V_S}{V_B}\right)\right]$$

$$c) \alpha = \frac{R_B}{R_2 + R_B}$$

$$d) \left(\frac{I_O}{I_S}\right) = 3360 \text{ ppm/}^\circ\text{C}, \left(\frac{R_B}{R_2}\right) = +750 \text{ ppm/}^\circ\text{C}$$

$$e) I_O = \frac{67.7\text{mV}}{R_1}$$

The design steps are straightforward:

- 1) Knowing V_S and the desired bridge voltage V_B , solve equation (b) for α .
- 2) Now, solve equation (c) for R_2 , letting $R_B = 4650\Omega$.
- 3) Solve equation (a) for I_O .
- 4) Find R_1 , or its nearest 1% tolerance value from equation (e).

Table II gives specific 1% resistor values in ohms, for several popular system voltages. For best results, the resistors should be 1% metal film with a low temperature coefficient.

Table II. Selected R Values vs V_S for Figure IV

V_S	V_B	$R_1(\Omega)$	$R_2(\Omega)$
5V	3V	147	11.0k
6V	4V	105	9.53k
9V	6V	68.1	9.53k
12V	9V	43.2	8.25k
15V	10V	41.2	9.53k

Amplifier Design

There are hundreds of instrumentation amplifier designs, and the intent here will be to briefly describe one circuit which:

- does not load the bridge
- involves minimal components
- provides excellent performance

The choice of the operational amplifiers to use is based on individual cost/performance trade-offs. The accuracy will be primarily limited by the amplifier's common-mode rejection, offset voltage drift with temperature and noise performance. Low cost, low performance devices, such as the LM324 can be used if the temperature range is limited to $25^\circ\text{C} \pm 15^\circ\text{C}$ and an accuracy of $\pm 2\%$ is adequate. For more precise applications, amplifiers such as the LT1014 and LT1002 have been found to be excellent.

An amplifier that uses a single supply is shown in Figure V. Table III gives resistor values for various supply and full-scale output combinations. Details of this basic amplifier are shown in SenSym Application Note #17 (SSAN-17).

Table III. For 0 to 70°C Operation

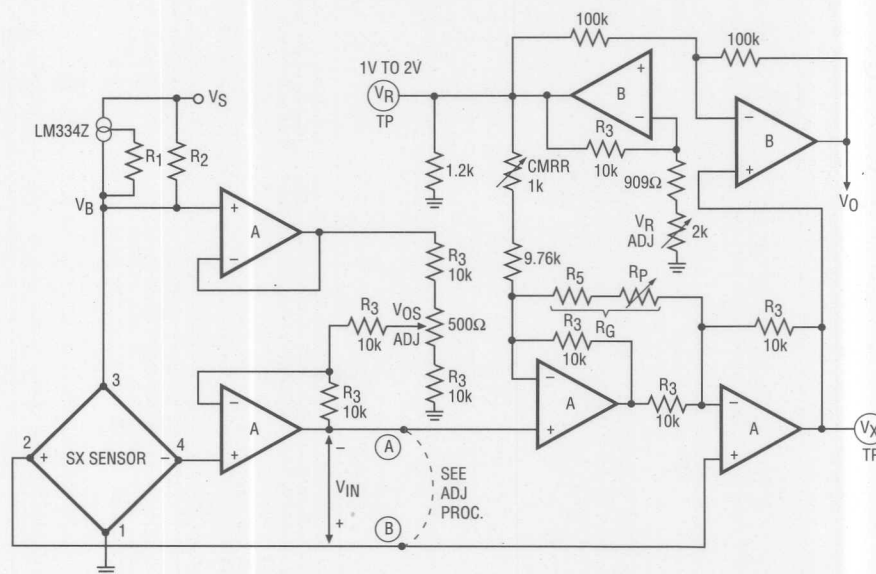
V_S	V_B	R_2	R_1	SPAN		
				FS	R_S	R_P
5V	3.5V	9.09k	118 Ω	3V	604 Ω	2k
6V	4.5V	8.45k	86.6 Ω	4V	604 Ω	2k
9V	7V	7.87k	54.9 Ω	5V	1k	2k
12V	10V	7.15k	36.5 Ω	5V	1.82k	5k
12V	10V	7.15k	36.5 Ω	10V	511 Ω	2k
15V	12V	7.68k	31.6 Ω	5V	1.4k	5k
15V	12V	8.87k	31.6 Ω	10V	604 Ω	2k

1. Without pressure applied,
 - (a) Short points A and B together as shown in Figure V. Adjust the 1k common-mode rejection (CMRR) pot until the voltage at test point (T_P) V_X is equal to the voltage at test point (T_P) V_R. This is easily accomplished by placing a digital voltmeter between these test points and adjusting for 0.000

- (b) Remove the short and adjust the 500Ω offset adjust pot until V_X is again equal to V_R .
- (c) Adjust the $2k$ reference (V_R) adjust pot to get an output voltage (V_O) equal to 1.00 V .
2. Apply the full-scale pressure and adjust the span adjust pot, R_5 , to get the output voltage that is desired to represent full-scale.

This application note provides the necessary information for temperature compensating and calibrating the SX sensors. In some cases, the customer may find that SX devices which have been factory adjusted for temperature compensation and span are more economical for a particular application. SenSym does offer devices with this feature. For more information on these factory calibrated and compensated devices, the SCX Series, please contact your nearest SenSym sales office or the SenSym factory.

1


$$V_0 = 4 \left[1 + \frac{10k}{R_G} \right] V_{IN} + V_R$$

Resistors Labeled R₃, R₄ Are 5-Element Resistor Arrays, 10k Ω . Two Required.

Figure V. Button Sensor Amplifier Circuit

ORDERING INFORMATION

To order, use the following part numbers:

Pressure Range	Order Part Number					
	Sensor in Button Package	Sensor in "N" Package	Sensor in TO Package (Open Bridge)	Sensor in ½ "N" Package	Sensor in Nipple Package	Sensor in DIP Package
0 to 15 psia	SX15A	SX15AN	SX15AHO	SX15AN2	SX15AP1	SX15AD1, 2, 3
0 to 30 psia	SX30A	SX30AN	SX30AHO	SX30AN2	SX30AP1	SX30AD1, 2, 3
0 to 100 psia	SX100A	SX100AN	SX100AHO	SX100AN2	—	SX100AD1, 2, 3
0 to 150 psia	SX150A	—	SX15AHO	—	—	SX150AD1, 2, 3
0 to 15 psid or psig	SX15D	SX15DN	SX15GSO	SX15DN2	SX15AP1	SX15DD1, 2, 3
0 to 30 psid or psig	SX30D	SX30DN	SX30GSO	SX30DN2	SX30AP1	SX30DD1, 2, 3
0 to 100 psid or psig	SX100D	SX100DN	SX100GSO	SX100DN2	—	SX100DD1, 2, 3
0 to 150 psid or psig	SX150D	—	SX150GSO	—	—	SX150DD1, 2, 3

See Section 9 for Package Styles and Dimensions

SPX50, SPX100, SPX200 Integrated Circuit Pressure Sensors

1

FEATURES

- **Low Cost**
- **0-7 psi to 0-30 psi Pressure Ranges**
- **Absolute and Differential (Gage) Devices**
- **<0.1% Full-scale Combined Linearity and Hysteresis Error**
- **Easily Mounted with Tie Wrap, Screws, or Soldered to PC Board.**
- **Small Internal Volume For Fast Response**

APPLICATIONS

- **Medical Equipment**
- **Automotive**
- **Computer Peripherals**
- **Industrial Controls**

GENERAL DESCRIPTION

The SPX Series feature an integrated circuit piezoresistive pressure sensor which provides an output voltage proportional to applied pressure. These devices use ion implanted resistors in an integral silicon diaphragm to transform the related shear stress, due to pressure, into an electrical output.

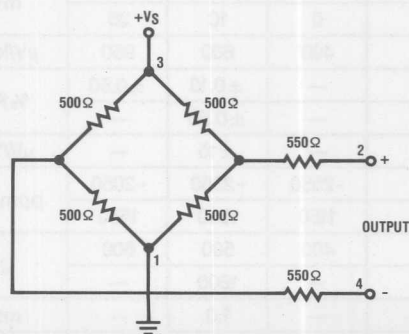
The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

The basic SPX package (i.e., SPX50D) has a compact plastic/aluminum housing which can be o-ring sealed or glued into a pressure connection fitting. The "N" package provides easy connections for plastic tubing. Both packages feature a standard 4-pin SIP for easy PC board mounting and electrical connection.

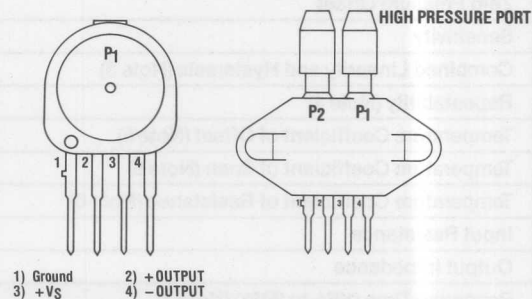
Although Sensym offers signal-conditioned transducers, these devices feature only the basic shear stress IC pressure sensor element. This greatly reduces unit cost and allows the electronic designer greater freedom in implementing transducer circuits. These devices are especially useful in applications requiring circuit flexibility, or compatibility with microprocessors.

SCHEMATIC DIAGRAM

(Equivalent Circuit)



ELECTRICAL CONNECTION



Note: Polarity applies for positive pressure applied to the high pressure port, P₁.

PRESSURE SENSOR CHARACTERISTICS

SPX50, SPX100, SPX200

Maximum Ratings (For All Devices)

Supply Voltage, V_S	6V _{DC}
Temperature Range	
Operating	-40°C to +125°C
Storage	-55°C to +125°C
Common-mode Line Pressure	60 psig
Lead Temperature	
(Soldering, 10 seconds)	300°C
Proof Pressure	Two Times Operating Pressure
Burst Pressure	Three Times Operating Pressure

SPX50 PERFORMANCE CHARACTERISTICS (See Note 1)

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range (Note 1)	0	—	50	kPa
Supply Current	—	6.0	—	mA _{DC}
Full-scale Span (Note 2)	40	60	95	mV
Zero Pressure Offset	0	20	35	
Sensitivity	800	1200	1900	μV/kPa
Combined Linearity and Hysteresis (Note 3)	—	±0.10	±0.50	%FS
Repeatability (Note 4)	—	±0.50	—	
Temperature Coefficient of Offset (Note 5)	—	±15	—	μV/°C
Temperature Coefficient of Span (Note 6)	-2550	-2350	-2050	ppm/°C
Temperature Coefficient of Resistance (Note 6)	1150	1350	1550	
Input Resistance	400	500	600	Ω
Output Impedance	—	1600	—	
Response Time (10% to 90%) (Note 7)	—	1.0	—	ms
Long Term Stability of Offset and Sensitivity (Note 8)	—	0.10	—	%FS

SPX100 PERFORMANCE CHARACTERISTICS (See Note 1)

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range (Note 1)	0	—	100	kPa
Supply Current	—	6.0	—	mA _{DC}
Full-scale Span (Note 2)	40	60	95	mV
Zero Pressure Offset	0	10	35	
Sensitivity	400	600	950	μV/kPa
Combined Linearity and Hysteresis (Note 3)	—	±0.10	±0.50	%FS
Repeatability (Note 4)	—	±0.50	—	
Temperature Coefficient of Offset (Note 5)	—	±15	—	μV/°C
Temperature Coefficient of Span (Note 6)	-2550	-2350	-2050	ppm/°C
Temperature Coefficient of Resistance (Note 6)	1150	1350	1550	
Input Resistance	400	500	600	Ω
Output Impedance	—	1600	—	
Response Time (10% to 90%) (Note 7)	—	1.0	—	ms
Long Term Stability of Offset and Sensitivity (Note 8)	—	0.10	—	%FS

SPX200 PERFORMANCE CHARACTERISTICS (See Note 1) SPX50, SPX100, SPX200

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range (Note 1)	0	—	200	kPa
Supply Current	—	6.0	—	mA _{DC}
Full-scale Span (Note 2)	40	60	95	mV
Zero Pressure Offset	0	10	35	
Sensitivity	200	300	475	μV/kPa
Combined Linearity and Hysteresis (Note 3)	—	±0.10	±0.50	%FS
Repeatability (Note 4)	—	±0.50	—	
Temperature Coefficient of Offset (Note 5)	—	±15	—	μV/°C
Temperature Coefficient of Span (Note 6)	-2550	-2350	-2050	ppm/°C
Temperature Coefficient of Resistance (Note 6)	1150	1350	1550	
Input Resistance	400	500	600	Ω
Output Impedance	—	1600	—	
Response Time (10% to 90%) (Note 7)	—	1.0	—	ms
Long Term Stability of Offset and Sensitivity (Note 8)	—	0.10	—	%FS

Specification Notes: (For All Devices)

Note 1: Reference Conditions: Supply Voltage, $V_S = 3V_{DC}$, $T_A = 25^\circ\text{C}$, Common-mode Line Pressure = 0 psig, Pressure Applied to P_1 ; 1.0kPa equals 0.145 psi.

Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.

Note 3: This is the algebraic sum of the percent of errors due to linearity and hysteresis given the following definitions:

$$\% \text{ FS error} = \frac{V_{1/2 \text{ full-scale}} - \left\{ \left(\frac{V_{\text{full-scale}} - V_{\text{offset}}}{\text{full-scale pressure}} \right) \times (1/2 \text{ full-scale pressure}) + V_{\text{offset}} \right\}}{2 V_{\text{full-scale}}} \times 100\%$$

Hysteresis — the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.

Note 4: Maximum difference in output at any pressure with the operating pressure range and temperature within $+10^\circ\text{C}$ to $+85^\circ\text{C}$ after:

- 100 temperature cycles, -40°C to $+125^\circ\text{C}$
- 1.0 million pressure cycles, 0kPa to full-scale span.

Note 5: Slope of the endpoint straight line from -40°C to $+125^\circ\text{C}$.

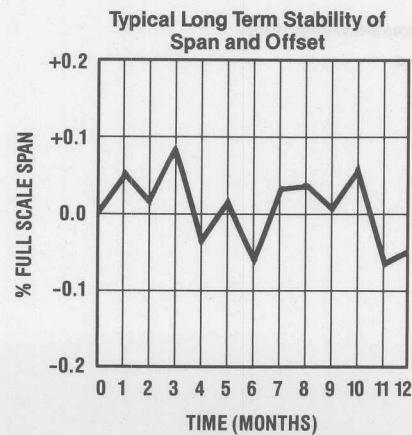
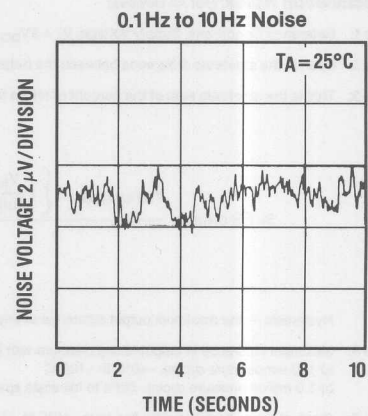
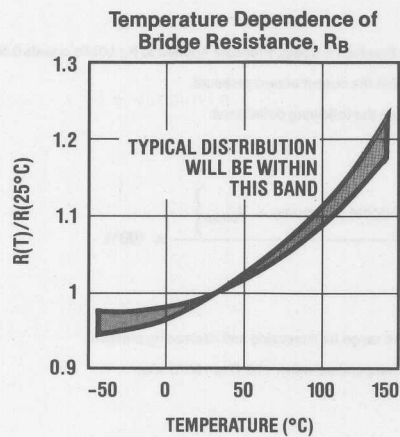
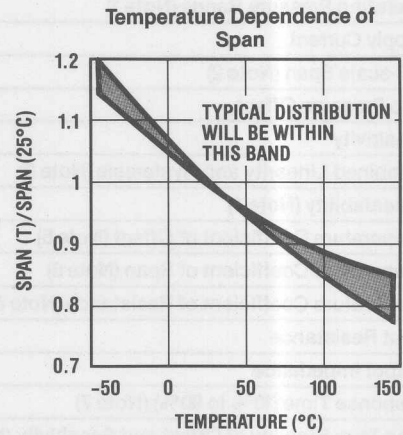
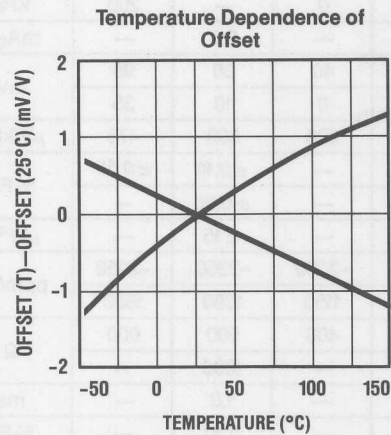
Note 6: This is the best straight line fit for operation between 0°C and 70°C . For operation outside this temperature, contact factory for more specific applications information.

Note 7: Response time for a 0kPa to full-scale span pressure step change.

Note 8: Long term stability over a one year period.

TYPICAL PERFORMANCE CHARACTERISTICS

SPX50, SPX100, SPX200



DEFINITION OF TERMS

General Terms

Absolute Pressure: Pressure measured relative to a vacuum. Usually expressed in pounds per square inch absolute (psia). Typically equated with barometric pressure.

Differential Pressure: The pressure difference measured between two pressure sources. Usually expressed in pounds per square inch differential (psid). When one source is a perfect vacuum, the pressure difference is called *absolute pressure*. When one source is the local ambient, the pressure is called *gage pressure*.

Gage Pressure: Pressure measured relative to ambient pressure (psig). Obtained by leaving one port of SPXxxD type devices open to the atmosphere.

kPa: Kilopascal 1.0 kPa equals 0.145 psi.

Vacuum: A perfect vacuum is the absence of gaseous fluid.

Transducer Parameters

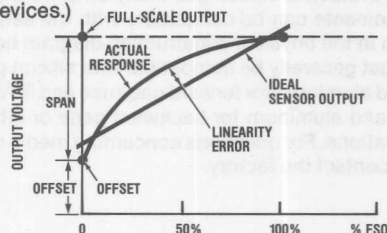
Burst Pressure: The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.

Common-Mode Pressure — Maximum: The maximum pressure that can be applied to both ports simultaneously of a differential transducer.

Full-Scale Output: The actual voltage reading obtained at the endpoint of the pressure range.

Linearity: The maximum deviation of measured output at constant temperature (25°C) from "best straight line" determined by three points (offset pressure, full-scale pressure, and one-half full-scale pressure).

Offset Voltage: The transducer output signal at zero pressure, (0 psig for gages and differential, 0 psia for absolute devices.)



SPX50, SPX100, SPX200

Operating Pressure Range: The specified range over which a transducer is intended to measure, specified by the upper and lower limits.

Over-Pressure — Maximum: The maximum *normal mode* (measured) pressure that can be applied without changing the transducer's performance or accuracy beyond the specified limits. This would be applied to either port of a differential transducer. This is also called proof pressure.

Reference Pressure: The pressure used as a reference in measuring transducer errors.

Reference Temperature: The temperature used as reference in measuring transducer errors.

Sensitivity: The ratio of output signal voltage change to the corresponding input pressure change. Sensitivity is determined by computing the ratio of span to the specified input pressure range.

Span: The arithmetic difference in transducer output signal measured at the specified minimum and maximum operating pressures. (Full-scale output — offset)

Temperature Coefficient of Offset Voltage: This defines how the offset voltage will change with temperature when a fixed voltage is applied to the bridge. For the SPX series, the offset TC is typically $\pm 15 \mu\text{V}/^\circ\text{C}$ with 3V applied to the bridge.

A straight line definition, using temperature end points, is used although the offset TC is slightly non-linear.

Temperature Coefficient of Resistance: This defines the manner in which the bridge input resistance changes with temperature. For the SPX series, the resistance TC is always positive at approximately $+1350 \text{ ppm}/^\circ\text{C}$. This means that for every 1°C rise in temperature, the resistance "seen" by the bridge voltage will typically rise by 0.135% of its nominal value.

Temperature Coefficient of Span: The span TC defines the manner in which the span/sensitivity changes with temperature. For the SPX series, the span TC is always negative at approximately $-2350 \text{ ppm}/^\circ\text{C}$. This means that for a fixed voltage applied to the bridge, the sensitivity will decrease 0.235% for every 1°C rise in temperature.

PRESSURE UNIT CONVERSION CONSTANTS

(Most Commonly Used — Per International Conventions)

	PSI ⁽¹⁾	In. H ₂ O ⁽²⁾	In. Hg ⁽³⁾	kPa	millibar	cm H ₂ O ⁽⁴⁾	mm Hg ⁽⁵⁾
PSI ⁽¹⁾	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
In. H ₂ O ⁽²⁾	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In. Hg ⁽³⁾	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
kPa	0.14504	4.0147	0.2953	1.000	20.000	20.2973	7.5006
millibar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H ₂ O ⁽⁴⁾	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg ⁽⁵⁾	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Notes: 1. PSI — pounds per square inch 2. at 39°F 3. at 32°F 4. at 4°C 5. at 0°C

MECHANICAL AND MOUNTING CONSIDERATIONS

Basic Sensor Element

The basic sensor element (i.e. SPX50D) was designed to allow easy interface with additional cases and housings which then allow pressure connection. The device can be mounted with an O-ring, gasket, or RTV seals on one or both sides of the device. The device can then be glued or clamped into a variety of fixtures and the leads can be bent as necessary to allow for ease of electrical connection. However, caution is advised as repeated bending of the leads will cause eventual breakage.

For absolute and gage applications, pressure should be applied to the top side of the device. (See Physical Construction Drawing.) For differential applications, the top side of the device (P_1) should be used as the high pressure port and the bottom (P_2) as the low pressure port.

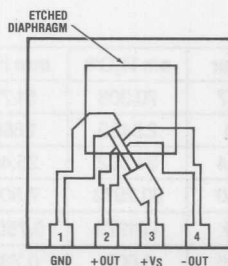
The basic SPX package has a very small internal volume which allows fast response in many applications. Typical internal volumes are 0.06 cubic centimeters for P_1 and 0.001 cubic centimeters for P_2 .

Packaged Sensor

The packaged sensor (i.e. SPX50DN) is designed for convenient pressure connection and easy PC board mounting. For mounting the device horizontally to the PC board, the leads can be bent down. The packaged sensor can be attached to the board using either tie wraps or standard mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

All versions of the packaged sensor have two (2) tubes available for pressure connection. For absolute devices only, the top port (P_1) is active. Applying pressure through the other port will result in pressure dead ending into the backside of the silicon sensor. If this occurs, the device will not give an output signal with pressure.

For gage devices, pressure is also intended to be applied to the top port (P_1). For differential pressure applications, the top port (P_1) should be used as the high pressure port and (P_2) should be used as the low pressure port.



Basic Sensor Chip

GENERAL DISCUSSION

Output Characteristics

The SPX series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port P_1 of the device. If the devices are operated in the backward gage mode, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage. Changes in supply voltage will cause changes in the transfer curves, offset voltage, and full-scale span.

User Calibration

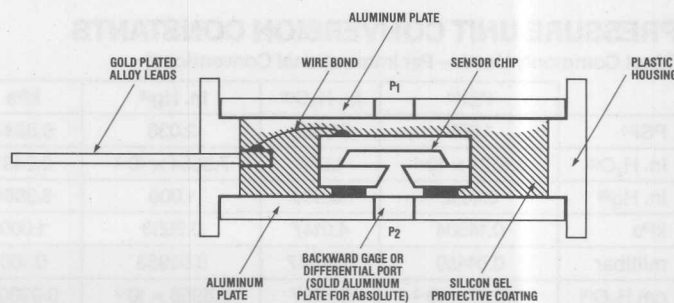
SPX series devices feature the basic IC pressure sensor element. This will keep overall system costs down by allowing the user to select calibration and temperature compensation circuits which specifically match individual application needs. In most cases, the primary signal conditioning elements to be added to the SPX by the user are: offset and span calibration and temperature compensation. Some typical circuits are shown in the application section.

Vacuum Reference (Absolute Devices)

Absolute sensors have a hermetically sealed-in vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a sealed-in vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

Media Compatibility

SPX devices are compatible with most non-corrosive gases. Because the circuitry on the devices is coated with a protective silicon gel, many otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below, fluids must generally be compatible with silicon gel, plastic, and aluminum for forward gage use and RTV, silicon, glass and aluminum for backward gage or differential applications. For questions concerning media compatibility, contact the factory.



Physical Construction

APPLICATION INFORMATION

General

The SPX family of pressure sensors functions as a Wheatstone bridge. When pressure is applied to the device (see Figure 1) the resistors in the arms of the bridge change by an amount, Δ .

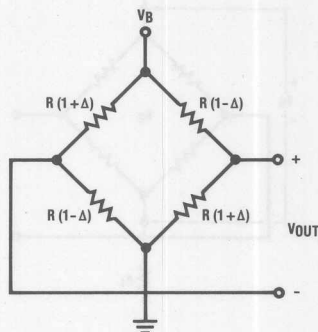


Figure 1.

The resulting differential output voltage V_O , is easily shown to be $V_O = V_B \times \Delta$. Since the change in resistance, is directly proportional to pressure, V_O can be written as:

$$V_O = S \times P \times V_B \pm V_{OS} \quad (1)$$

Where: V_O is the output voltage in mV.

S is the sensitivity in mV/V per psi

P is the pressure in psi

V_B is the bridge voltage in volts.

V_{OS} , is the offset error (the differential output voltage when the applied pressure is zero). The offset voltage presents little problem in most applications, since it can easily be corrected for in the amplifier circuitry, or corrected digitally if a microprocessor is used in the system.

Temperature Effects

In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a dot (·) over the variable. for example,

$$\dot{S} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{\partial S}{\partial T}$$

From equation (1), and ignoring the V_{OS} term, it is seen that for a given constant pressure, the output voltage change, as a function of temperature*, is:

$$\dot{V}_O = \dot{S} P V_B \quad (2)$$

*It should be noted that temperature in this discussion is the temperature of the silicon die. The die temperature will be dependent upon internal power dissipation, ambient temperature and, in some cases, the working fluid temperature.

SPX50, SPX100, SPX200

Thus, in order for output voltage to be independent of temperature, the voltage across the bridge, V_B , must change with temperature in the "opposite direction" from the sensitivity change with temperature. From the typical curves for the temperature dependence of span (span = $S \times P \times V_B$), it can be seen that the sensitivity change with temperature is slightly non-linear and can be correlated very well with an equation of the form:

$$S = S_0 \left[(1 - \beta T_D) + \epsilon T_D^2 \right] \quad (3)$$

where T_D is the temperature difference between 25°C and the temperature of interest, S_0 is the sensitivity at 25°C, and beta (β) and rho (ϵ) are correlation constants. Fortunately, between 0°C and 70°C the change in sensitivity with temperature is quite linear, and excellent results can be obtained over this temperature range by ignoring the second-order temperature dependent term. Operating outside the 0°C to 70°C temperature range will require a more rigorous mathematical approach and the use of non-linear compensating circuitry, if accuracy of better than $\pm 1\%$ is required. Because the majority of SPX applications fall within the 0°C to 70°C operating temperature range, the discussion and circuit designs given here will ignore the non-linear effects.

Thus:

$$S = S_0 (1 - \beta T_D) \quad (4)$$

Substituting equation (4) into equation (1), and ignoring V_{OS} , it can be shown that the necessary bridge voltage, V_B , will be of the form:

$$V_B = \frac{V_{BO}}{(1 - \beta T_D)} = V_{BO} \left[(1 + \beta T_D + (\beta T_D)^2 + \dots) \right]$$

where V_{BO} is the bridge voltage at 25°C.

This equation is again non-linear. However, for the temperature range of interest, and since β is small (0.235%/°C from the electrical tables), the above expression can be accurately approximated by:

$$V_B = V_{BO} \left[1 + \beta T_D \right]$$

with less than 1% error. Thus to compensate for a negative 2350 ppm/°C sensitivity change with temperature, the bridge voltage should increase with temperature at a rate of +2350 ppm/°C.

The above value of bridge voltage change will be used in the circuit discussions that follow. That is to say, the required change in terms of ppm/°C is:

$$\left(\frac{\dot{V}_B}{V_B} \right) = +2350 \text{ ppm/°C.}$$

APPLICATION INFORMATION (Continued)

The bridge input resistance*, R_B , also changes with temperature and is quite linear in the temperature range of interest. The bridge resistance has a temperature coefficient of typically:

$$\left(\frac{\dot{R}_B}{R_B}\right) = +1350 \text{ ppm/}^\circ\text{C}.$$

This term enters into several compensation circuit equations, particularly when the bridge excitation is from a constant current source.

To summarize, the following list indicates how the sensor variables can be accommodated:

- Full-scale span from device to device:
Make the gain adjustment in the op amp circuitry
- Temperature coefficient of sensitivity:
1) temperature compensate the bridge or
2) temperature compensate the op amp gain
- Offset voltage:
Adjustment in op amp circuitry
- Offset voltage temperature coefficient:
Usually can be ignored. For more precise design requirements, contact the factory for information on how to compensate for this term.

Bridge Compensation Circuits

Although thermistors can be used to temperature compensate the bridge (and in fact will be required for extended temperature operation), they are inherently non-linear, difficult to use in volume production, and more expensive than the circuit approaches shown here, which use inexpensive semiconductor devices. The circuits shown have been designed to incorporate a minimum number of adjustments and allow interchangeability of devices with little variation from device to device.

In general, equations for the bridge voltage and its change with temperature are given to enable the user to modify or adjust the circuitry as required.

1. Diode String (Figure 2)

For systems using 5V or 6V supplies, this method of compensating for the effects of span over temperature is the lowest cost solution. The diodes are small signal silicon diodes, such as 1N914 or 1N4148, and do not have to be matched. The diodes should have a forward drop (ϕ) of about 0.7V at 6mA current.

**The input resistance is the resistance "seen" by the bridge voltage, V_B , with no power applied.

SPX50, SPX100, SPX200

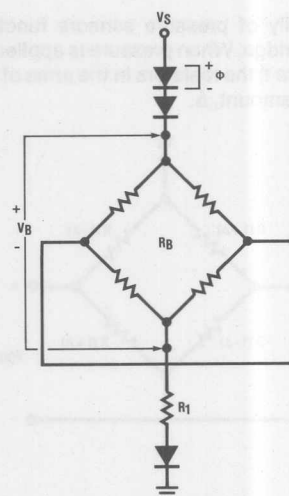


Figure 2. Diode String Span Compensation

$$a) V_B = \alpha [V_S - 3\phi]$$

$$b) \left(\frac{\dot{V}_B}{V_B}\right) = \frac{\left(\frac{\dot{R}_B}{R_B}\right)}{\left(1 + \frac{R_B}{R_1}\right)} - \frac{3\left(\frac{\phi}{\phi}\right)}{\left(\frac{V_S}{\phi} - 3\right)}$$

$$c) \alpha = \frac{R_B}{R_1 + R_B}$$

$$d) \left(\frac{\phi}{\phi}\right) \approx -2500 \text{ ppm/}^\circ\text{C for silicon diodes}$$

Figure 2 Equations

For example, solving equation (b) for R_1 when

$$V_S = 5.0 \text{ V}$$

$$\phi = 0.7 \text{ V}$$

$$\frac{\dot{R}_B}{R_B} = +1350 \text{ ppm/}^\circ\text{C}$$

$$\frac{\dot{V}_B}{V_B} = 2350 \text{ ppm/}^\circ\text{C}$$

$$R_B = 500 \Omega$$

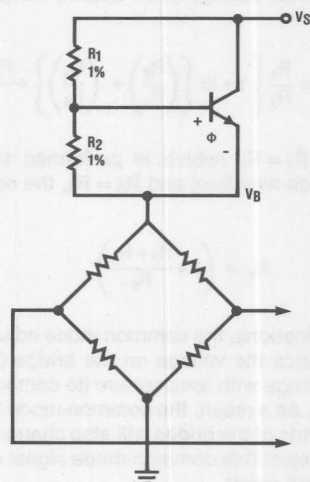
Gives: $R_1 = 333 \Omega$ (use closest 1% tolerance, 332 Ω)

Substituting this value of R_1 into equation (c) to solve for α and then using equation (a) will result in a bridge voltage of $V_B = 1.74 \text{ V @ } 25^\circ\text{C}$. This can then be used with equation (1) to determine the expected span. If precision temperature compensation is required for each device, resistor R_1 should be a 500 Ω pot.

For operation with $V_S = 6V$, four diodes (with no resistor) in series will result in a bridge voltage of about 3.2V and a temperature coefficient of about 2200 ppm/°C.

2. Transistor Compensation Network

Figure 3 uses a single transistor to simulate a diode string, with the equations as shown. The values shown in Table 1 were found to give excellent results over 0°C to 100°C. Again, if precision temperature compensation is required for each device, resistor R_1 should be a 500Ω pot.



$$a) V_B = V_S - \alpha \phi$$

$$b) \left(\frac{\dot{V}_B}{V_B} \right) = - \left(\frac{\dot{\phi}}{\phi} \right) \left(\frac{\alpha}{\frac{V_S}{\phi} - \alpha} \right)$$

$$c) \alpha = 1 + \frac{R_1}{R_2}$$

$$d) \left(\frac{\dot{\phi}}{\phi} \right) \approx -2500 \text{ ppm/}^\circ\text{C}$$

Figure 3.

V_S	$R_1\Omega$	$R_2\Omega$
5V	402	150
6V	429	133

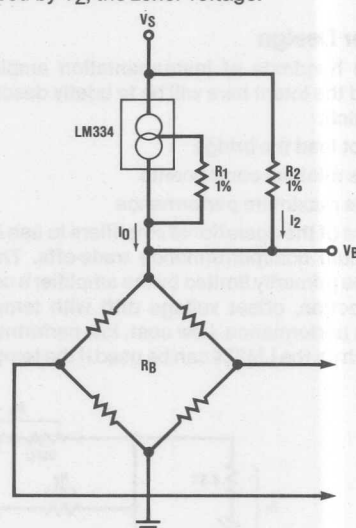
Table 1. Selected R Values vs. V_S for Figure 3.

3. Constant Current Excitation (Figure 4)

The circuits shown in Figures 2 and 3, although simple and inexpensive, have one drawback in that the voltage across the bridge is determined by the compensation network. That is, the compensation network is determined and what voltage is "leftover" is across the bridge. The circuit of Figure 4 solves this problem and

allows the bridge voltage to be independently selected. In Figure 4, the bridge is driven from a constant current source, the LM334, which has a very well known and repeatable temperature coefficient of +3300 ppm/°C. This temperature coefficient (TC), in conjunction with the TC of the bridge resistance, is too high to compensate the sensitivity TC, hence resistor R_2 is added to reduce the total circuit TC.

The circuit of Figure 4 is also the preferred circuit to use in battery operated equipment. For battery operation, the top of resistor R_2 should be connected to a micropower reference voltage zener such as the LM336. In this manner, the voltage across the bridge is compensated for temperature but is totally independent of the battery voltage. The equations given will still apply, provided V_S is replaced by V_Z , the zener voltage.



$$a) V_B = \alpha (V_S + I_O R_2)$$

$$b) \left(\frac{\dot{V}_B}{V_B} \right) = \left(\frac{\dot{R}_B}{R_B} \right) (1 - \alpha) + \left(\frac{\dot{I}_O}{I_O} \right) \left[1 - \alpha \left(\frac{V_S}{V_B} \right) \right]$$

$$c) \alpha = \frac{R_B}{R_2 + R_B}$$

$$d) \left(\frac{\dot{I}_O}{I_O} \right) = 3300 \text{ ppm/}^\circ\text{C}, \frac{\dot{R}_B}{R_B} = +1350 \text{ ppm/}^\circ\text{C}$$

$$e) I_O = \frac{67.7 \text{ mV}}{R_1}$$

Figure 4.

The design steps are straightforward:

- 1) Knowing V_S and the desired bridge voltage V_B , solve equation (b) for α .
- 2) Now, solve equation (c) for R_2 , letting $R_B = 500\Omega$.
- 3) Solve equation (a) for I_O .
- 4) Find R_1 , or its nearest 1% tolerance value from equation (e).

Table 2 gives experimentally determined, specific 1% resistor values in ohms, for several popular system voltages which will result in V_B of approximately $3.0V_{DC}$ @ 25°C . For best results, the resistors should be 1% metal film with a low temperature coefficient.

V_S	R_1	R_2
5V	16.9	866
9V	24.9	1700
12V	24.9	2440

Table 2. Selected R Values vs. V_S for Figure 4.

Amplifier Design

There are hundreds of instrumentation amplifier designs, and the intent here will be to briefly describe one circuit which:

- does not load the bridge
- involves minimal components
- provides maximum performance

The choice of the operational amplifiers to use is based on individual cost/performance trade-offs. The accuracy will be primarily limited by the amplifier's common-mode rejection, offset voltage drift with temperature and noise performance. Low cost, low performance devices, such as the LM324 can be used if the temperature

range is limited to $25^\circ\text{C} \pm 15^\circ\text{C}$ and an accuracy of $\pm 2\%$ is adequate. For more precise applications, amplifiers such as the LT1014 and LT1002 have been found to be excellent. For example, a design using the temperature compensation circuit shown in Figure 4, in conjunction with the op amp circuit shown in Figure 5, exhibited a worst case full-scale span error of less than 0.8% from 0°C to 100°C , with the error being less than 0.2% from 25°C to 75°C .

For the amplifier configuration shown, the gain equation is:

$$A_V = \frac{V_O}{V_{IN}} = \frac{R_4}{R_3} \left[1 + \frac{1}{2} \left\{ \left(\frac{R_2}{R_1} \right) + \left(\frac{R_3}{R_4} \right) \right\} + \frac{R_2 + R_3}{R_5} \right]$$

By setting: $R_1 = R_2$ (which is performed to set the common-mode rejection) and $R_3 = R_4$, the equation is simplified to:

$$A_V = \left(2 + \frac{R_2 + R_3}{R_5} \right)$$

In most applications, the common-mode adjustment is necessary since the voltage on the bridge (V_B) is designed to change with temperature (to compensate for the span TC). As a result, the common-mode voltage at the output arms of the bridge will also change. The amplifier must reject this common-mode signal or considerable error will result.

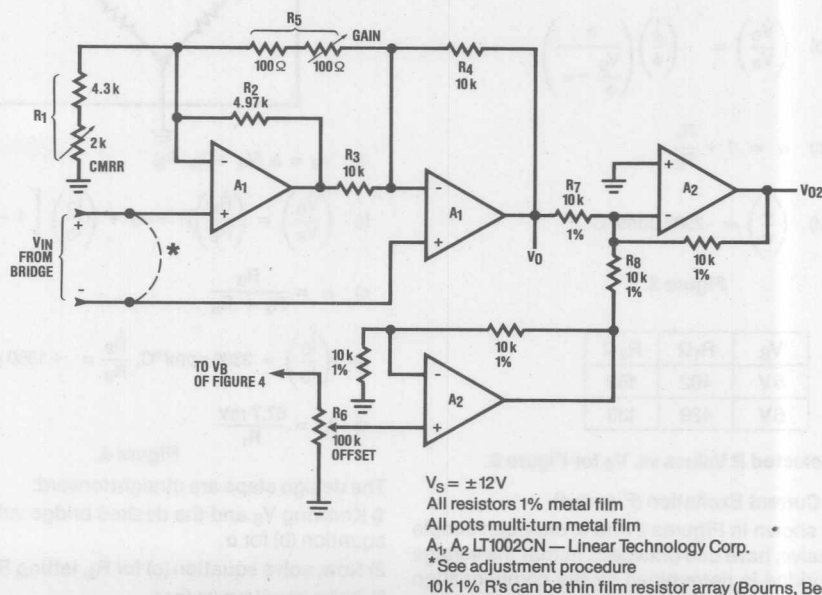


Figure 5.

APPLICATION INFORMATION (Continued)

SPX50, SPX100, SPX200

Factory Compensated Devices

This application note provides the necessary information for temperature compensating and calibrating the SPX sensors. In some cases, the customer may find that SPX devices which have been factory adjusted for temperature compensation and span are more economical for a particular application. Sensym does offer devices with this feature. For more information on these factory calibrated and compensated SPX series devices, please contact your nearest Sensym sales office or the Sensym factory.

Adjustment Procedure:

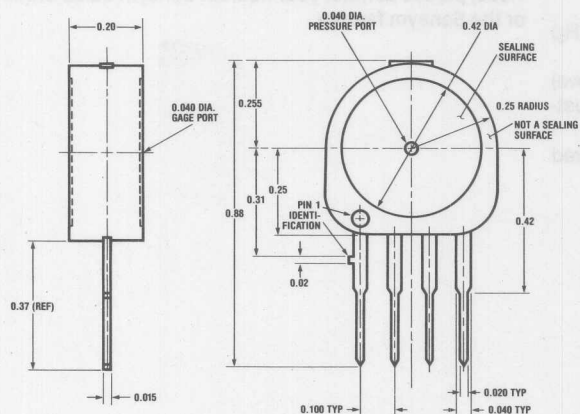
A. With zero input pressure:

1. Adjust the common-mode rejection by adjusting R_1 . This can be quickly and accurately done by jumpering the two bridge arms together (see dashed line in Figure 5) and adjusting R_1 until the voltage at V_O is at 0.000 V.
2. Adjust the offset voltage (R_6) to set the output voltage at V_{O2} to be 0.000 V.

- ##### B. Apply the full-scale pressure and adjust the gain (R_5) to give the desired output span voltage at V_{O2} .
- Because the initial offset adjustment (step 2 above) was made for an unknown gain, the offset adjustment (R_6) will have to be readjusted. This process should be repeated until the desired span is obtained.

PHYSICAL DIMENSIONS

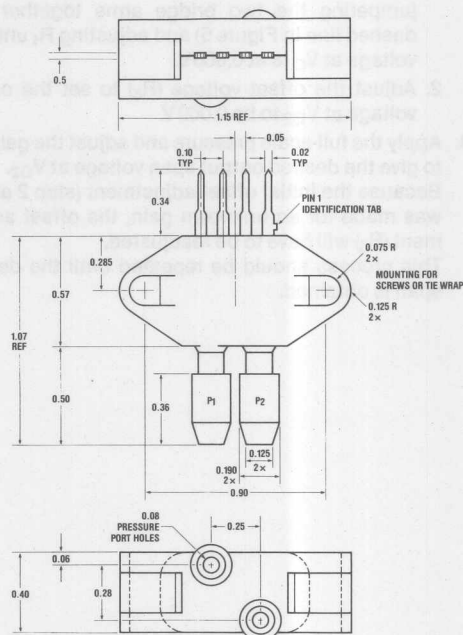
Button Sensor SPXxxA,D



TYPICAL WEIGHT: 1 GRAM

SPX50, SPX100, SPX200

Packaged Sensor Element (N Package) SPXxxA,D(N)



TYPICAL WEIGHT: 4.5 GRAMS

ORDERING INFORMATION

To order, use the following part numbers:

Basic Sensor Element

Absolute:

0-15 psia SPX100A

0-30 psia SPX200A

Differential and Gage:

0-7 psid SPX50D

0-15 psid SPX100D

0-30 psid SPX200D

Packaged Sensor (N Package)

Absolute:

0-15 psia SPX100AN

0-30 psia SPX200AN

Differential and Gage:

0-7 psid SPX50DN

0-15 psid SPX100DN

0-30 psid SPX200DN

SenSym

SLP004D 0 - 4 In. H₂O

LOW PRESSURE SENSORS

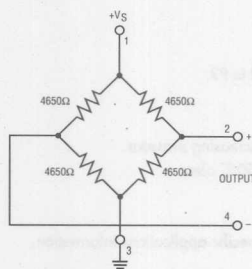
FEATURES

- Accurate Low Pressure Readings
- Low Cost
- High Impedance Bridge
- Low Noise
- Low power Consumption for Battery Operation

APPLICATIONS

- Medical Instrumentation
- Portable and Battery Powered Equipment
- Air Flow Monitoring
- HVAC
- Industrial Controls

EQUIVALENT CIRCUIT



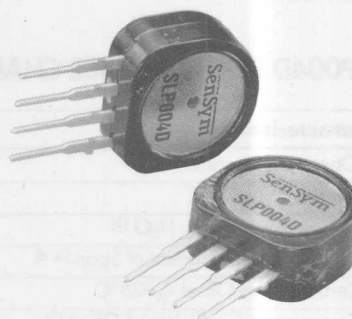
Note: Polarity applies for positive pressure applied to port, P2

GENERAL DESCRIPTION

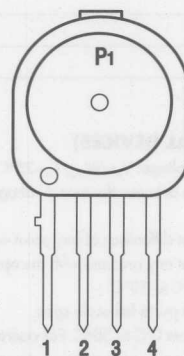
The SLP Series of pressure sensors provides the lowest cost components for measuring very low pressures. These low pressure range devices were specifically designed to accurately measure differential and gage pressures of 0 to 4 inches of H₂O. They are meant for use with non-corrosive and non-ionic media, such as air, dry gases and the like.

These differential devices allow application of pressure to either side of the diaphragm and can be used for gage or differential pressure measurements.

For further technical information on the SLP Series, please contact the factory.



ELECTRICAL CONNECTION



- 1) +V_s 2) + OUTPUT
3) GROUND 4) - OUTPUT

BUTTON PACKAGE

ABSOLUTE MAXIMUM RATINGS (For All Devices)

Supply Voltage (V)	7.5V _{DC}
Temperature Range	
Operating	0 to 50°C
Storage	0 to 70°C
Common-mode Pressure	150 In. H ₂ O
Lead Temperature	
(Soldering, 10 seconds)	300°C
Proof Pressure	10 In. H ₂ O
Burst Pressure ⁽⁹⁾	5 psi or 150 In. H ₂ O

SLP004D PERFORMANCE CHARACTERISTICS ⁽¹⁾

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure	—	—	4	In. H ₂ O
Sensitivity T _A =25°C	+1700	+2500	+5500	μV/V/In. H ₂ O
Full-scale Span 4 In. H ₂ O ⁽²⁾	+34	+50	+110	mV
Temperature Coefficient of Span ^(5, 8)	-2850	-2400	-1950	ppm/°C
Zero Pressure Offset T _A =25°C	-40	0	+40	mV
Temperature Coefficient of Offset ⁽⁵⁾	—	±4	—	μV/V/°C
Combined Linearity and Hysteresis ⁽³⁾	—	0.5	1.0	%FS
Long Term Stability of Offset and Sensitivity ⁽⁷⁾	—	0.5	—	%FS
Response Time (10% to 90%) ⁽⁶⁾	—	0.5	—	ms
Input Resistance T _A =25°C	—	4.65	—	kΩ
Temperature Coefficient of Resistance ^(5, 8)	+2100	+2300	+2500	ppm/°C
Output Impedance	—	4.70	—	kΩ
Repeatability ⁽⁴⁾	—	0.2	—	%FS
Position Sensitivity	—	50	—	μV/V/g

SPECIFICATION NOTES: (FOR ALL DEVICES)

Note 1: Reference Conditions: Supply Voltage, V_S=5V_{DC}, T_A=25°C, Common-mode Line Pressure=0 psig, Pressure Applied to P2.

Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure.

Note 3: See Definition of Terms.

Hysteresis—the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.

Note 4: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +50°C after:

a) 1,000 temperature cycles, 0°C to 50°C

b) 1.5 million pressure cycles, 0 psi to full-scale span.

Note 5: Slope of the best straight line from 0°C to 50°C. For operation outside this temperature, contact factory for more specific applications information.

Note 6: Response time for a 0 psi to full-scale span pressure step change. 10% to 90% Rise Time

Note 7: Long term stability over a one year period.

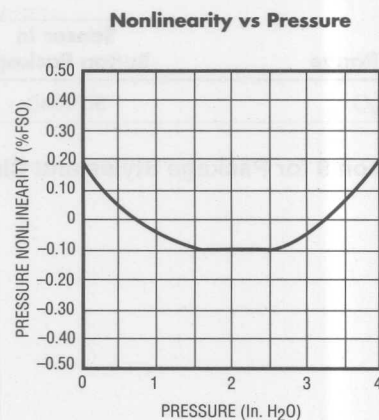
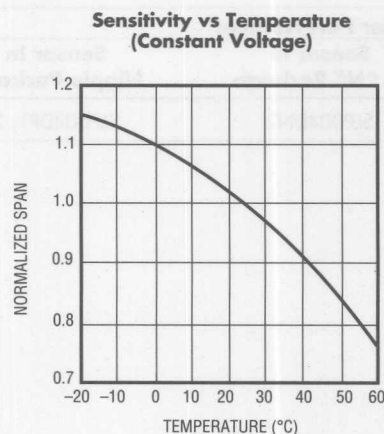
Note 8: This parameter is not 100% tested. It is guaranteed by process design and tested on a sample basis only.

Note 9: If the maximum burst pressure is exceeded, even momentarily, the package may leak or burst, or the pressure sensing die may fracture.

WARNING:

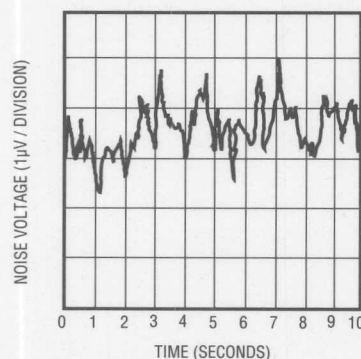
Due to the delicate nature of these very sensitive devices, some special handling is required. Parts are sensitive to shock and vibration and must be handled with care. Dropping on any hard surface (bench top etc.) can destroy the device. Note 10" H₂O overpressure.

TYPICAL PERFORMANCE CHARACTERISTICS



1

0.1 Hz to 10 Hz Noise



APPLICATION INFORMATION

GENERAL INFORMATION

The SLP family of pressure sensors function as a wheatstone bridge. When pressure is applied to the device the resistors in the arms of the bridge change as shown in Figure 1.

The resulting differential output voltage, V_O , is easily shown to be $V_O = V_B \times \Delta R$. Since the change in resistance is directly proportional to pressure, V_O can be written as:

$$V_O = S \times P \times V_B + V_{OS}$$

where: V_O is the output voltage in mV

S is the sensitivity in mV/V psi

P is the pressure in psi

V_B is the bridge voltage in volts

V_{OS} is the offset error, (the differential output voltage when the applied pressure is zero).

For a complete application discussion, see SenSym's SCC Series Datasheet.

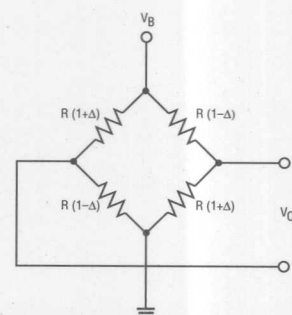


Figure 1.

ORDERING INFORMATION

To order, use the following part numbers:

Pressure Range	Order Part Number		
	Sensor In Button Package	Sensor In ½ "N" Package	Sensor In Nipple Package
0 to 4 In. H ₂ O	SLP004D	SLP004DN2	SLP004DP1, 2

See Section 9 for Package Styles and Dimensions

SenSym

SOLID STATE SENSORS

SCC "ISO" SERIES

0 to 15 psia, 0 to 100 psia

PRESSURE SENSORS

FEATURES

- Rugged Plastic Package
- Advanced Polymer Isolation
- Low Cost
- Internal Temperature Compensation

APPLICATIONS

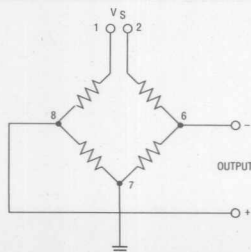
- Oceanographic Equipment
- Medical Equipment

ELECTRICAL CONNECTION



- 1, 2) +V_S 7) GROUND
8) +V_{OUT} 6) -V_{OUT}
3, 4, 5) No Connect

EQUIVALENT CIRCUIT



GENERAL DESCRIPTION

The SCC "ISO" Series sensors are a rugged, low cost substitute for the stainless steel pressure sensors currently used in aqueous applications. Advanced polymer technology allows production of this rugged device using low cost plastic without degradation of device durability or performance. Constructed out of precision injected molded Ultem® in conjunction with a unique polymer isolation membrane, the SCC "ISO" sensors are ideal for pressure measurement of many types of aqueous media, including salt water and medical saline solutions. Typical applications of these sensors include oceanographic equipment such as sonobuoys and depth gauges as well as medical equipment.

For stability over temperature, the sensors feature internal temperature compensation, ensuring precise operation between 0°C to +50°C. Typical specifications include linearity within $\pm 0.5\%$ FSO (full-scale output), and temperature error of 0.25%/°C. The high impedance 5.0K bridge is ideal for low power or battery operated applications.

The piezoresistive sensor chip is housed in a compact package and isolated from measured media by a resilient polymer membrane. This package is easily mounted using o-ring seals, ensuring reliable, leak-free operation. Standard TO-5 pin-out is provided for electrical connection.

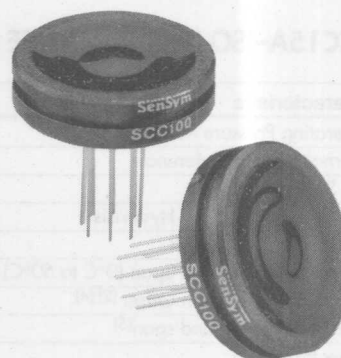
The SCC "ISO" series is designed to give the OEM user the best in price and performance for any application involving mea-

surement of specific aqueous media such as water, salt water and saline solution. Incorporating sophisticated but low cost materials, this product gives outstanding performance at an extraordinarily low price.

For further information, please contact your local SenSym representative or the SenSym factory

MEDIA COMPATIBILITY

The SCC "ISO" Series has been designed for use with water based media including salt water and medical saline solutions. The SCC "ISO" is not recommended for use with gases or solvents such as gasoline..



PHYSICAL CHARACTERISTICS**MAXIMUM RATINGS****Maximum Supply Current**
Temperature Range

1.5mA

Compensated	0°C to +50°C
Operating	-20°C to +85°C
Storage	-40°C to +105°C

Maximum Overpressure Pressure

SCC15A-ISO	30 psia
SCC100A-ISO	150 psia

SCC15A-ISO PERFORMANCE CHARACTERISTICS (1)

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range	0	—	15	psia
Internal Vacuum Reference	—	10 ⁻³	—	psi
Full Scale Span	40	65	95	mV
Combined Linearity & Hysteresis	—	0.5	1.0	%FS
Zero Pressure Offset (2)	-30.0	-10.0	20.0	mV
Temperature Effect on Span (0°C to 50°C) (3)	—	0.50	1.50	%FS
Temperature Effect on Offset (2) (4)	—	0.50	2.00	%FS
Stability of Offset and span (5)	—	0.10	—	%FS
Repeatability (6)	—	0.2	—	%FS
Input Impedance	—	5.0	—	K Ω
Output Impedance	4.0	5.0	6.5	K Ω

SCC100A-ISO PERFORMANCE CHARACTERISTICS (1)

Characteristics	Min.	Typ.	Max.	Unit
Operating Pressure Range	0	—	100	psia
Internal Vacuum Reference	—	10 ⁻³	—	psi
Full Scale Span	85	150	225	mV
Combined Linearity & Hysteresis	—	0.5	1.0	%FS
Zero Pressure Offset (2)	-30.0	-10.0	20.0	mV
Temperature Effect on Span (0°C to 50°C) (3)	—	0.50	1.50	%FS
Temperature Effect on Offset (2) (4)	—	0.50	2.00	%FS
Stability of Offset (5)	—	0.10	—	%FS
Repeatability (6)	—	0.2	—	%FS
Input Impedance	—	5.0	—	K Ω
Output Impedance	4.0	5.0	6.5	K Ω

SPECIFICATION NOTES: (FOR ALL DEVICES)

Note 1: Unless otherwise noted, performance characteristics apply at reference condition of $I_S=1.0\text{mA}$ at $T_A=25^\circ\text{C}$.

Note 2: Zero pressure offset is at 0 psia.

Note 3: This is the typical temperature shift for span when measured between 0°C and 50°C relative to the 25°C reading.
Typical temperature coefficients for span and resistance are -2200ppm/°C and +2200ppm/°C respectively.

Note 4: This is the typical temperature shift for offset when measured between 0°C and 50°C relative to the 25°C reading.
Guaranteed by design. Not 100% product tested.

Note 5: Typical offset stability over a 6 month period.

Note 6: Maximum difference in offset after:

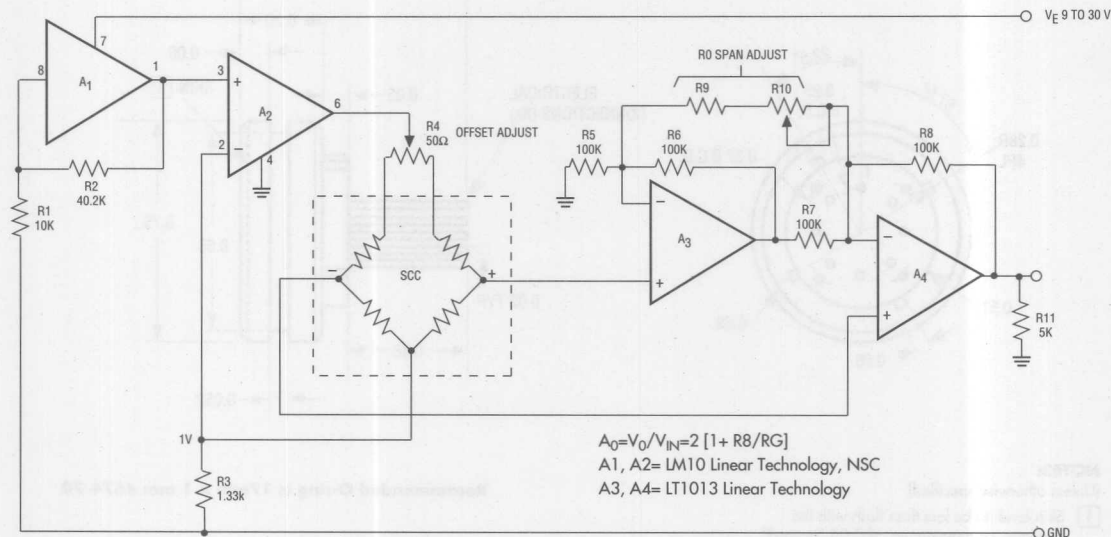
1) 100 temperature cycles, 0°C to 50°C.

2) 100,000 pressure cycles, 0 psi to full-scale span.

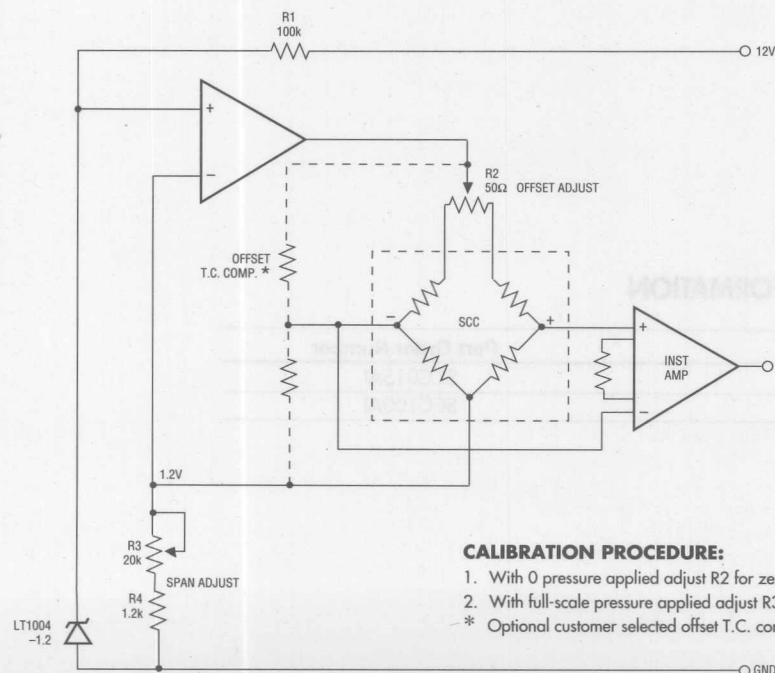
*See SCC datasheet for current source application notes.

APPLICATION INFORMATION

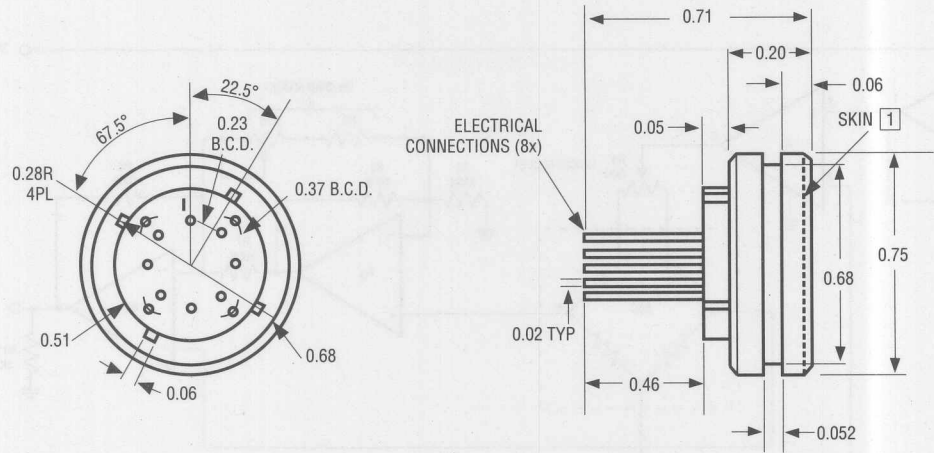
AMPLIFIER CIRCUIT WHICH PROVIDES 0-5V OR 0-10V OUTPUT



TYPICAL CALIBRATION CIRCUIT



PHYSICAL DIMENSIONS



NOTES:

(Unless otherwise specified)

- 1 Skin level: to be less than flush with the package, or a maximum of 0.05 "inward" (As shown)

Recommended O-ring is 17mm x 1 mm #674-70

ORDERING INFORMATION

Pressure Range	Part Order Number
0 to 15 psia	SCC015AI
0 to 100 psia	SCC100AI

SOLID STATE SENSORS

SenSym

2

SECTION 2

CALIBRATED AND TEMPERATURE COMPENSATED SENSORS

SECTION TABLE OF CONTENTS

SCX Series	2-3
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SOLID STATE SENSORS

SenSym

Sensym

SCX01, SCX05, SCX15,
SCX30, SCX100, SCX150
0 to 1psi to 0 to 150psi

Precision Compensated Pressure Sensors

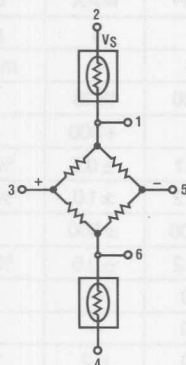
FEATURES

- Precision Temperature Compensation
- Calibrated Zero and Span
- Small Size
- Low Noise
- High Accuracy
- High Impedance for Low Power Applications

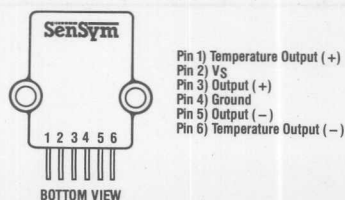
APPLICATIONS

- Medical Equipment
- Barometry
- Computer Peripherals
- Pneumatic Controls
- HVAC

EQUIVALENT CIRCUIT



ELECTRICAL CONNECTION



Note: The polarity indicated is for pressure applied to port B.
(For Absolute devices pressure is applied to port A
and the output polarity is reversed.)

GENERAL DESCRIPTION

The SCX series sensors will provide a very cost effective solution for pressure applications that require high accuracy over a wide temperature range. These internally calibrated and temperature compensated sensors were specifically designed to provide an accurate and stable output over a 0°C to 70°C temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

Devices are available to measure absolute, differential, and gage pressures from 1psi (SCX01) up to 150psi (SCX150). The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the pressure sensing diaphragm and can be used for gage or differential pressure measurements.

The SCX devices feature an integrated circuit sensor element and laser trimmed thick film ceramic housed in a compact nylon case. This package provides excellent corrosion resistance and provides isolation to external package stresses. The package has convenient mounting holes and pressure ports for ease of use with standard plastic tubing for pressure connection.

All SCX devices are calibrated for span to within $\pm 1\%$ and provide a very low zero pressure output of ± 300 microvolts maximum. Thus, for many applications, no trimming networks are required in the signal conditioning circuitry. If the application requires extended temperature range operation, beyond 0 to 70°C, two pins which provide an output voltage proportional to temperature are available for use with external circuitry.

The output of the bridge is ratiometric to the supply voltage and operation from any D.C. supply voltage up to +30V is acceptable.

Because these devices have very low noise and excellent temperature compensation, they are ideal for medical and other high performance applications. The 100 microsecond response time also makes this series an excellent choice for computer peripherals and pneumatic control applications.

For further technical information on the SCX series, please contact your local Sensym office or the factory.

PRESSURE SENSOR CHARACTERISTICS

SCX01, SCX05, SCX15,
SCX30, SCX100, SCX150

STANDARD PRESSURE RANGES

PART NUMBER	OPERATING PRESSURE	PROOF PRESSURE*	FULL-SCALE SPAN
SCX01DN	0 – 1 psid	20 psid	18mV
SCX05DN	0 – 5 psid	20 psid	60mV
SCX15AN	0 – 15 psia	30 psia	90mV
SCX15DN	0 – 15 psid	30 psid	90mV
SCX30AN	0 – 30 psia	60 psia	90mV
SCX30DN	0 – 30 psid	60 psid	90mV
SCX100AN	0 – 100 psia	150 psia	100mV
SCX100DN	0 – 100 psid	150 psid	100mV
SCX150AN	0 – 150 psia	150 psia	90mV
SCX150DN	0 – 150 psid	150 psid	90mV

* Maximum pressure above which causes permanent sensor failure.

Maximum Ratings (For All Devices)

Supply Voltage, V_S +30 V_{DC}
 Common-mode Pressure 50 psig
 Lead Temperature 300°C
 (Soldering, 10 seconds)

Environmental Specifications (For All Devices)

Temperature Range 0 to 70°C
 Compensated – 40°C to +85°C
 Operating – 55°C to +125°C
 Storage 0 to 100% RH
 Humidity Limits

SCX01DN PERFORMANCE CHARACTERISTICS (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	1	psid
Sensitivity	—	18	—	mV/psi
Full-scale Span (Note 2)	17.82	18.00	18.18	mV
Zero Pressure Offset	– 300	0	+300	μV
Combined Linearity and Hysteresis (Note 3)	—	±0.1	±0.5	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	±0.2	±1.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	±100	±500	μV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

PRESSURE SENSOR CHARACTERISTICS (Cont.)**SCX01, SCX05, SCX15,
SCX30, SCX100, SCX150****SCX05DN PERFORMANCE CHARACTERISTICS** (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	5	psid
Sensitivity	—	12.0	—	mV/psi
Full-scale Span (Note 2)	59.4	60.0	60.6	mV
Zero Pressure Offset	− 300	0	+300	μ V
Combined Linearity and Hysteresis (Note 3)	—	± 0.1	± 0.5	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	± 0.2	± 1.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	± 100	± 500	μ V
Repeatability (Note 5)	—	± 0.2	± 0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	± 0.1	—	%FSO

SCX15 PERFORMANCE CHARACTERISTICS (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	15	psi
Sensitivity	—	6.0	—	mV/psi
Full-scale Span (Note 2)	89.10	90.0	90.90	mV
Zero Pressure Offset (Note 11)	− 300	0	+300	μ V
Combined Linearity and Hysteresis (Note 3)	—	± 0.1	± 0.5	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	± 0.2	± 1.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	± 100	± 500	μ V
Repeatability (Note 5)	—	± 0.2	± 0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	± 0.1	—	%FSO

PRESSURE SENSOR CHARACTERISTICS (Cont.)**SCX01, SCX05, SCX15,
SCX30, SCX100, SCX150****SCX30 PERFORMANCE CHARACTERISTICS (Note 1)**

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	30	psi
Sensitivity	—	3.0	—	mV/psi
Full-scale Span (Note 2)	89.1	90.0	90.9	mV
Zero Pressure Offset (Note 11)	– 300	0	+ 300	μ V
Combined Linearity and Hysteresis (Note 3)	—	± 0.1	± 0.5	% FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	± 0.2	± 1.0	% FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	± 100	± 500	μ V
Repeatability (Note 5)	—	± 0.2	± 0.5	% FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	± 0.1	—	% FSO

SCX100 PERFORMANCE CHARACTERISTICS (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	100	psi
Sensitivity	—	1.0	—	mV/psi
Full-scale Span (Note 2)	99.0	100.0	101.0	mV
Zero Pressure Offset (Note 11)	– 300	0	+ 300	μ V
Combined Linearity and Hysteresis (Note 3)	—	± 0.1	± 0.5	% FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	± 0.2	± 1.0	% FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	± 100	± 500	μ V
Repeatability (Note 5)	—	± 0.2	± 0.5	% FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	± 0.1	—	% FSO

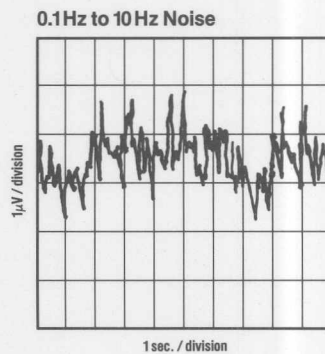
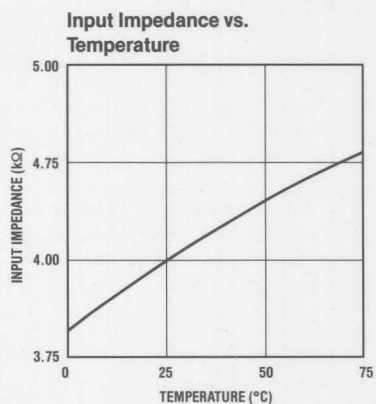
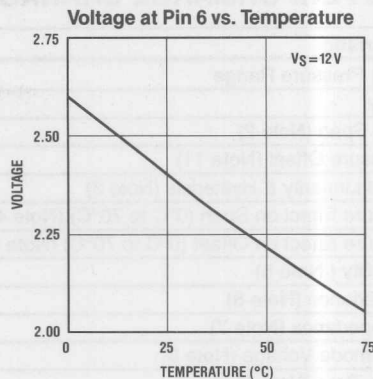
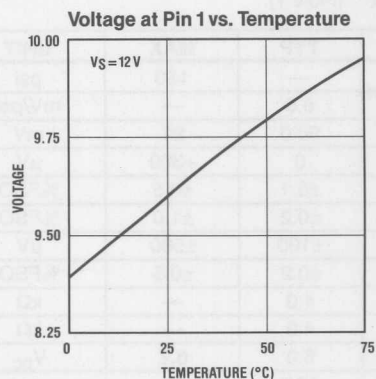
PRESSURE SENSOR CHARACTERISTICS (Cont.) **SCX01, SCX05, SCX15** **SCX30, SCX100, SCX150**

SCX150 PERFORMANCE CHARACTERISTICS (Note 1)

Characteristic	MIN	TYP	MAX	UNIT
Operating Pressure Range	—	—	150	psi
Sensitivity	—	0.6	—	mV/psi
Full-scale Span (Note 2)	89	90.0	91	mV
Zero Pressure Offset (Note 11)	-300	0	+300	μV
Combined Linearity & Hysteresis (Note 3)	—	±0.1	±0.5	%FSO
Temperature Effect on Span (0°C to 70°C) (Note 4)	—	±0.2	±1.0	%FSO
Temperature Effect on Offset (0°C to 70°C) (Note 4)	—	±100	±500	μV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.8	6.0	6.2	V _{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

TYPICAL PERFORMANCE CHARACTERISTICS

SCX01, SCX05, SCX15,
SCX30, SCX100, SCX150



Specification Notes: (For All Devices)

- Note 1:** Reference Conditions: Unless otherwise noted: Supply Voltage, $V_S = 12V_{DC}$, $T_A = 25^\circ C$, Common-mode Line Pressure = 0 psig, Pressure Applied to Port B. For absolute devices only, pressure is applied to Port A and the output polarity is reversed.
- Note 2:** Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Span is ratiometric to the supply voltage.
- Note 3:** See Definition of Terms.
Hysteresis — the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
- Note 4:** Maximum error band of the offset voltage and the error band of the span, relative to the $25^\circ C$ reading.
- Note 5:** Maximum difference in output at any pressure with the operating pressure range and temperature within $0^\circ C$ to $+70^\circ C$ after:
a) 1,000 temperature cycles, $0^\circ C$ to $+70^\circ C$
b) 1.5 million pressure cycles, 0 psi to full-scale span.
- Note 6:** Input impedance is the impedance between pins 2 and 4.
- Note 7:** Output impedance is the impedance between pins 3 and 5.
- Note 8:** This is the common-mode voltage of the output arms (Pins 3 and 5) for $V_S = 12V_{DC}$.
- Note 9:** Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time.
- Note 10:** Long term stability over a one year period.
- Note 11:** Maximum zero pressure offset for absolute devices is $0 \pm 500 \mu V$.

SCX01, SCX05, SCX15, SCX30, SCX100, SCX150

2

GENERAL DISCUSSION

The SCX series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port P_B of the device. If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage and full-scale span. Since for absolute device pressure is applied to port P_A , output polarity will be reversed.

User Calibration

The SCX devices are fully calibrated for offset and span and should therefore require little if any user adjustment in most applications. For precise span and offset adjustments, refer to the applications section herein.

Vacuum Reference (Absolute Devices)

Absolute sensors have a hermetically sealed vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

Media Compatibility

SCX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective

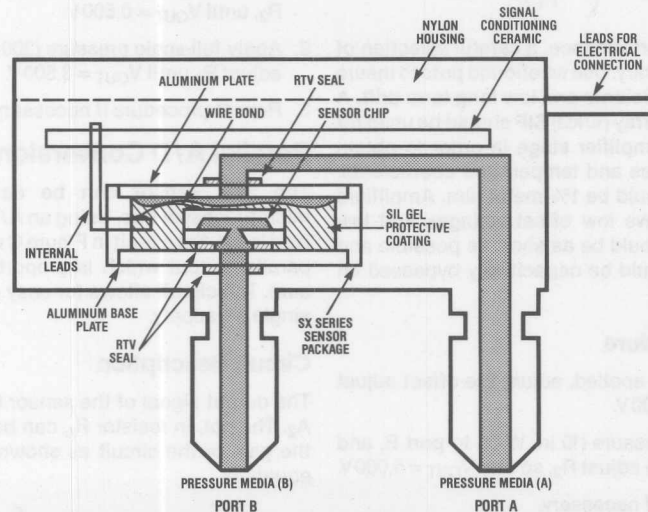
silicon gel, many otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below, fluids must generally be compatible with silicon gel, plastic, aluminum, RTV, silicon, and glass for use with Port B. For questions concerning media compatibility, contact the factory.

MECHANICAL AND MOUNTING CONSIDERATIONS

The SCX nylon housing is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

All versions of the SCX sensors have two (2) tubes available for pressure connection. For absolute devices, only port P_A is active. Applying pressure through the other port will result in pressure dead ending into the backside of the silicon sensor and the device will not give an output signal with pressure.

For gage applications, pressure should be applied to port P_B . Port P_A is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port P_B should be used as the high pressure port and P_A should be used as the low pressure port.



Physical Construction (Cutaway Diagram)

(Not Drawn to Scale)

SCX01, SCX05, SCX15, SCX30, SCX100, SCX150

APPLICATION INFORMATION

The following circuits show some typical designs using the SCX series sensors. For specific applications information or assistance, please contact your nearest Sensym sales office or the Sensym factory.

Low Pressure Applications

For sensing pressure below 1 psi, the circuit shown in Figure A uses the SCX01DN to provide a 2 to 5V output for a 0 to 10 inch of water column input pressure. This output signal is compatible with many A/D converters and hence can be used to interface to a microprocessor system. This low-cost circuit is easily adaptable to lower full-scale pressure down to 5 inches of water column.

Circuit Description

The LM10 is used to provide a voltage reference for the excitation voltage (V_E), and for the voltage node V_{REF} . With this configuration, V_E and V_{REF} are not affected by noise or voltage variations in the 12V power supply. R_3 is used to adjust V_{REF} to set the initial offset voltage at the output, V_{OUT} .

The pressure signal, V_{IN} , is amplified by amplifiers B_1 and B_2 . (See Sensym Application Note SSAN-17 for details on this amplifier) R_2 is used to adjust the signal gain of the circuit. The output equation is given below.

$$V_{OUT} = V_{IN} \left[2 \left(1 + \frac{R}{R_1} \right) \right] + V_{REF}$$

For the best circuit performance, a careful selection of components is necessary. Use wirebound pots to insure low temperature coefficients and low long-term drift. A five-element resistor array (10k Ω) SIP should be used for the resistors in the amplifier stage in order to obtain closely matched values and temperature coefficients. All other resistors should be 1% metal film. Amplifiers B_1 and B_2 should have low offset voltages and low noise. Signal lines should be as short as possible and the power supply should be capacitively bypassed on the PC board.

Adjustment Procedure

1. With zero-pressure applied, adjust the offset adjust R_3 , until $V_{OUT} = 2.000V$.
2. Apply full-scale pressure (10 in. W.C.) to port B, and adjust the full-scale adjust R_2 , so that $V_{OUT} = 5.000V$.
3. Repeat procedure if necessary.

Medical Applications

For blood pressure monitoring applications, the circuit shown in Figure B provides a 0.5V to 3.5V output for a 0 to 300mm Hg input pressure. The circuit is easily calibrated and is not affected by changes in the voltage supply. Because 300mm Hg is approximately 5.8 psi, an SCX05DN is used.

Circuit Description

The circuit shown here in Figure B is very similar to that shown in Figure A. The internal 200mV reference voltage of the LM10 is amplified to provide power to the sensor and to provide a voltage reference, V_{REF} . This allows the circuit to operate at a supply voltage between 5 and 20 volts without effecting the performance of the circuit. By adjusting R_3 , V_{REF} is used to set the initial zero-pressure voltage at V_{OUT} . The pressure signal, V_{IN} , is amplified by amplifiers B_1 and B_2 . These amplifiers should be precision op amps with low offset voltages and high common-mode rejection. The signal gain is adjusted by R_2 , and the overall equation for the output voltage is given by,

$$V_{OUT} = V_{IN} \left[2 \left(1 + \frac{R}{R_1} \right) \right] + V_{REF}$$

Adjustment Procedure

1. With zero-pressure applied, adjust the offset adjust R_3 , until $V_{OUT} = 0.500V$.
2. Apply full-scale pressure (300mm Hg) to port B, and adjust R_2 until $V_{OUT} = 3.500V$.
3. Repeat procedure if necessary.

Parallel A/D Conversion

The SCX sensor can be easily interfaced to a microprocessor bus. Using an A/D converter, for a 0 to 1 psig input, the circuit in Figure C will provide an eight-bit parallel output which is proportional to applied pressure. The circuit allows for easy calibration and uses a single 5V supply.

Circuit Description

The output signal of the sensor is amplified by A_1 , and A_2 . The pot, in resistor R_1 , can be adjusted to calibrate the gain of the circuit as shown in the following gain equation:

$$V_{OUT} = V_{IN} 2 \left[1 + \frac{R}{R_1} \right]$$

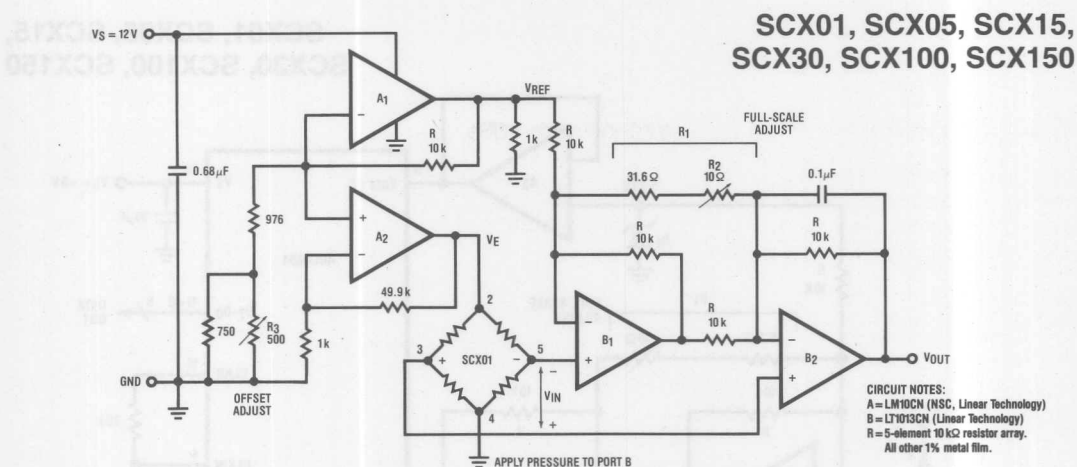


Figure A. Low Pressure Circuits Provide a 2 to 5V Output for a 0-10 in. W.C. Pressure Input.

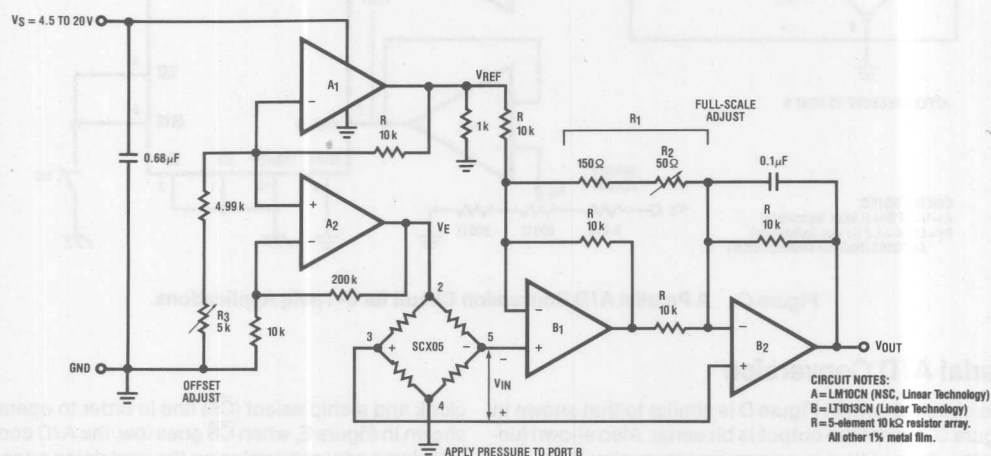


Figure B. Medical Application Circuit Provides a 0.5 to 3.5V Output for a 0-300 mmHg Pressure Input

Parallel A/D Conversion (Cont.)

By adjusting R_3 , $V_{IN}(-)$ on the A/D converter is used to adjust the initial offset voltage. A zener diode (LT1004) sets the initial input voltage and provides the reference voltage for the converter. The converter will output the maximum digital code when the A/D converter's input voltage, V_{OUT} , is twice the zener voltage, minus $1\frac{1}{2}$ LSB. The A/D converter, as shown, is a free-running configuration where the binary output is updated continuously.* The only requirement is that the WR and $INTR$ must be momentarily grounded after power-up to ensure proper operation.

Adjustment Procedure

1. With no pressure applied, adjust the offset pot R_3 until all bits are zero except the LSB, which should be switching between one and zero.
2. Apply full-scale pressure (1 psig) to port B, and adjust the full-scale pot R_2 until all bits are ones except the LSB which should be flickering between one and zero.
3. Repeat procedure if necessary.

*For timing specifications and bus interface, see the ADC0804 Datasheet from National Semiconductor.

SCX01, SCX05, SCX15, SCX30, SCX100, SCX150

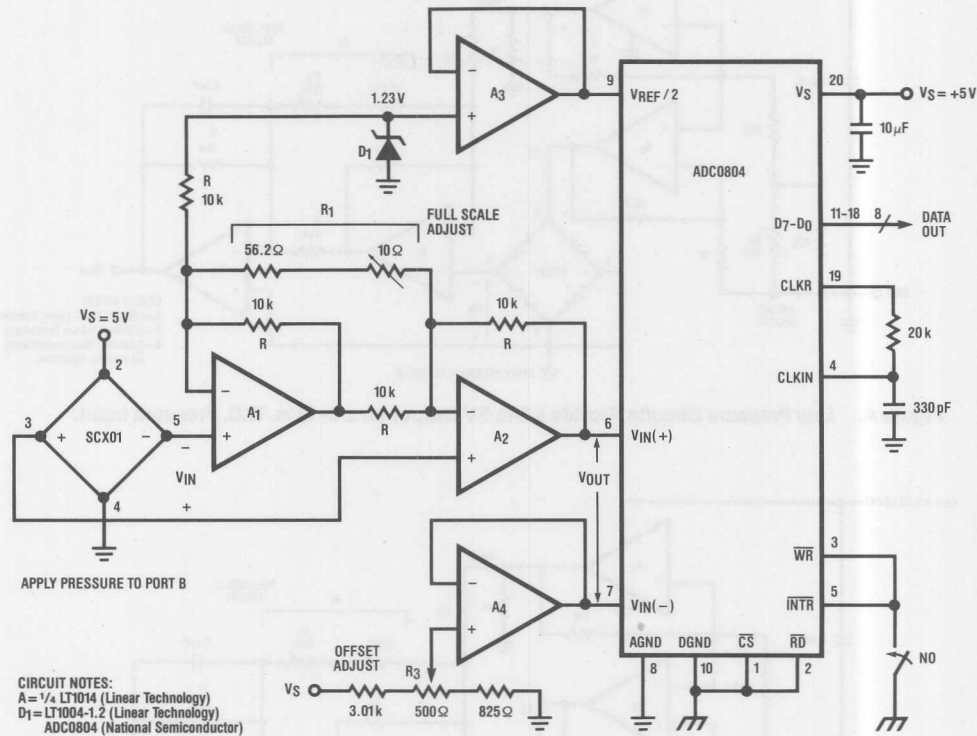


Figure C. A Parallel A/D Conversion Circuit for 0-1 psig Applications.

Serial A/D Conversion

The circuit shown in Figure D is similar to that shown in Figure C, except the output is bit serial. Also shown (under the dashed line) is a complimentary circuit for converting the serial output to a parallel output for simplified testing.

Circuit Description

The three op amp configuration allows V_{OUT} to be at the same common-mode voltage as V_{IN} , and takes advantage of the excellent CMRR of the ADC0831. R_2 is used to adjust the gain of the amplifier such that

$$V_{OUT} = V_{IN} \left[\frac{3}{2} + \frac{2R}{R_1} \right]$$

The A/D converter will output the maximum digital code when V_{OUT} is equal to the zener voltage minus 1 1/2 LSB. the initial offset of the circuit can be nulled out by adjusting pot R_3 . The converter circuit requires only a

clock and a chip select ($\overline{CS}$) line in order to operate. As shown in Figure E, when $\overline{CS}$ goes low, the A/D converter will start a new conversion on the next rising edge of the clock. On the next falling edge of the clock, D_0 will have a zero start bit. Then, starting with the MSB, the data out line (D_0) will provide the converted digital output during the next eight consecutive falling edges of the clock. The serial output can be read by using an oscilloscope, a microprocessor, or a simple serial-to-parallel converter as shown in Figure D.

Adjustment Procedure

1. With zero-pressure, adjust R_3 , until the output of the A/D converter is alternating between 00 and 01 (HEX).
2. Apply full-scale pressure (1 psig) to port B, and adjust R_4 until the digital output alternates between the FE to FF transition.
3. Repeat procedure if necessary.

SCX01, SCX05, SCX15, SCX30, SCX100, SCX150

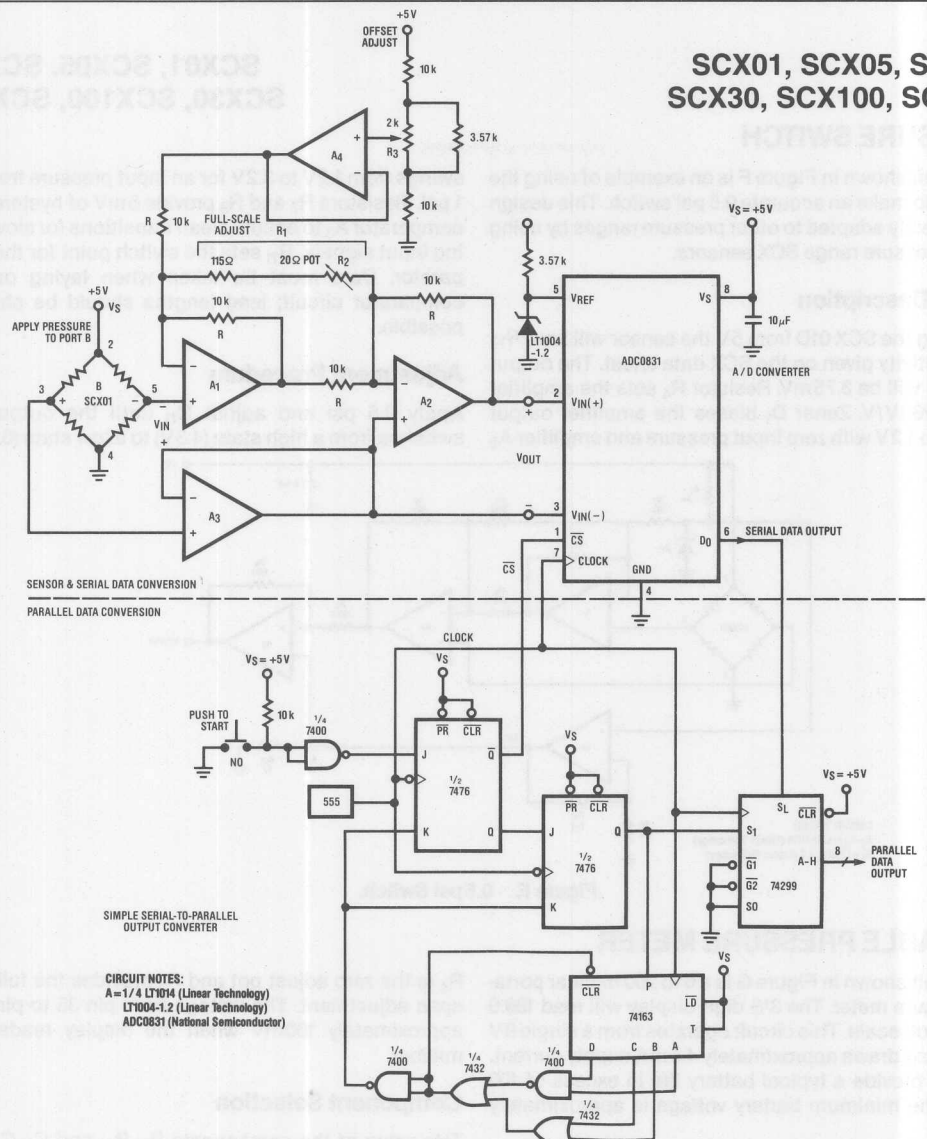


Figure D. Serial A/D Conversion for 0-1 psig Applications and Simple Test Circuit.

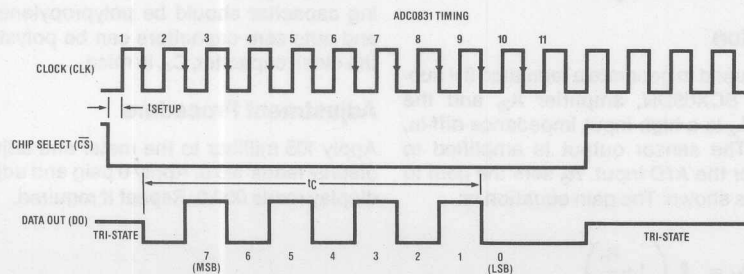


Figure E. Timing Diagram.

SenSym

SCX C Series 0 to 1psi to 0 to 150psi Low Cost Compensated Pressure Sensors

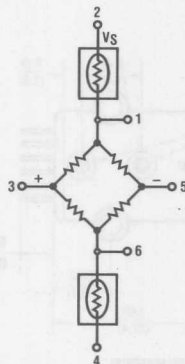
FEATURES

- Low Cost
- Temperature Compensation
- Calibrated Zero and Span
- Small Size
- Low Noise
- High Impedance for Low Power Applications

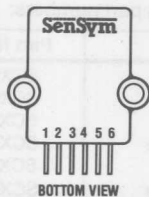
APPLICATIONS

- Medical Equipment
- Computer Peripherals
- Pneumatic Controls
- HVAC

EQUIVALENT CIRCUIT



ELECTRICAL CONNECTION



- Pin 1) Temperature Output (+)
- Pin 2) Vs
- Pin 3) Output (+)
- Pin 4) Ground
- Pin 5) Output (-)
- Pin 6) Temperature Output (-)

Note: The polarity indicated is for pressure applied to port B.
(For Absolute devices, pressure is applied to port A
and the output polarity is reversed.)

GENERAL DESCRIPTION

The SCX C series sensors will provide a very cost effective solution for pressure applications that require operation over a wide temperature range. These internally calibrated and temperature compensated sensors give an accurate and stable output over a 0°C to 70°C temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

Devices are available to measure absolute, differential, and gage pressures from 1psi (SCX01) up to 150psi (SCX150). The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The Differential (D) devices allow application of pressure to either side of the pressure sensing diaphragm and can be used for gage or differential pressure measurements.

The SCX devices feature an integrated circuit sensor element and laser trimmed thick film ceramic housed in a compact nylon case. This package provides excellent corrosion resistance and provides isolation to external package stresses. The package has convenient mounting holes and pressure ports for ease of use with standard plastic tubing for pressure connection.

All SCX devices are calibrated for span to within $\pm 5\%$ and provide an offset (zero pressure output) of ± 1 millivolt maximum. These parts were designed for low cost applications where the user can typically provide fine adjustment of zero and span in external circuitry. For higher accuracies, refer to the standard SCX series datasheet. If the application requires extended temperature range operation, beyond 0 to 70°C, two pins which provide an output voltage proportional to temperature are available for use with external circuitry.

The output of the bridge is ratiometric to the supply voltage and operation from any D.C. supply voltage up to +30V is acceptable.

Because these devices have very low noise and 100 micro-second response time they are an excellent choice for medical equipment, computer peripherals, and pneumatic control applications.

For further technical information on the SCX series, please contact your local Sensym office or the factory.

PRESSURE SENSOR CHARACTERISTICS

SCX C Series

STANDARD PRESSURE RANGES

PART NUMBER	OPERATING PRESSURE	PROOF PRESSURE*	FULL-SCALE SPAN
SCX01DNC	0 – 1 psid	20 psid	18mV
SCX05DNC	0 – 5 psid	20 psid	60mV
SCX15ANC	0 – 15 psia	30 psia	90mV
SCX15DNC	0 – 15 psid	30 psid	90mV
SCX30ANC	0 – 30 psia	60 psia	90mV
SCX30DNC	0 – 30 psid	60 psid	90mV
SCX100ANC	0 – 100 psia	150 psia	100mV
SCX100DNC	0 – 100 psid	150 psid	100mV
SCX150ANC	0 – 150 psia	150 psia	90mV
SCX150DNC	0 – 150 psid	150 psid	90mV

* Maximum pressure above which causes permanent sensor failure.

Maximum Ratings (For All Devices)

Supply Voltage, V_s	+30 V_{DC}
Common-mode Pressure	50 psig
Lead Temperature (Soldering, 10 seconds)	300°C

Environmental Specifications (For All Devices)

Temperature Range	0 to 70°C
Compensated	– 40°C to +85°C
Operating	– 55°C to +125°C
Storage	0 to 100% RH
Humidity Limits	

SCX01DNC PERFORMANCE CHARACTERISTICS (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	1	psid
Sensitivity	—	18	—	mV/psi
Full-scale Span (Note 2)	17.00	18.00	19.00	mV
Zero Pressure Offset	– 1.0	0	+1.0	mV
Combined Linearity and Hysteresis (Note 3)	—	± 0.2	± 1.0	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	± 0.4	± 2.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	± 0.20	± 1.0	mV
Repeatability (Note 5)	—	± 0.2	± 0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V_{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	± 0.1	—	%FSO

PRESSURE SENSOR CHARACTERISTICS (Cont.)**SCX C Series****SCX05DNC PERFORMANCE CHARACTERISTICS** (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	5	psid
Sensitivity	—	12.0	—	mV/psi
Full-scale Span (Note 2)	57.5	60.0	62.5	mV
Zero Pressure Offset	−1.0	0	+1.0	mV
Combined Linearity and Hysteresis (Note 3)	—	±0.1	±1.0	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	±0.4	±2.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	±0.20	±1.0	mV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

SCX15C PERFORMANCE CHARACTERISTICS (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	15	psi
Sensitivity	—	6.0	—	mV/psi
Full-scale Span (Note 2)	85.0	90.0	95.0	mV
Zero Pressure Offset	−1.0	0	+1.0	mV
Combined Linearity and Hysteresis (Note 3)	—	±0.1	±1.0	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	±0.4	±2.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	±0.20	±1.0	mV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V _{DC}
Response Time (Note 9)	—	100	—	μ sec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

PRESSURE SENSOR CHARACTERISTICS (Cont.)**SCX C Series****SCX30C PERFORMANCE CHARACTERISTICS** (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	30	psi
Sensitivity	—	3.0	—	mV/psi
Full-scale Span (Note 2)	85.0	90.0	95.0	mV
Zero Pressure Offset	−1.0	0	+1.0	mV
Combined Linearity and Hysteresis (Note 3)	—	±0.2	±1.0	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	±0.4	±2.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	±0.2	±1.0	mV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V _{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

2**SCX100C PERFORMANCE CHARACTERISTICS** (Note 1)

CHARACTERISTIC	MIN	TYP	MAX	UNIT
Operating Pressure Range		—	100	psi
Sensitivity	—	1.0	—	mV/psi
Full-scale Span (Note 2)	95.0	100.0	105.0	mV
Zero Pressure Offset	−1.0	0	+1.0	mV
Combined Linearity and Hysteresis (Note 3)	—	±0.2	±1.0	%FSO
Temperature Effect on Span (0–70°C) (Note 4)	—	±0.4	±2.0	%FSO
Temperature Effect on Offset (0–70°C) (Note 4)	—	±0.20	±1.0	mV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V _{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

PRESSURE SENSOR CHARACTERISTICS (Cont.)

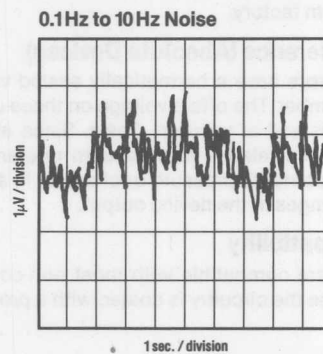
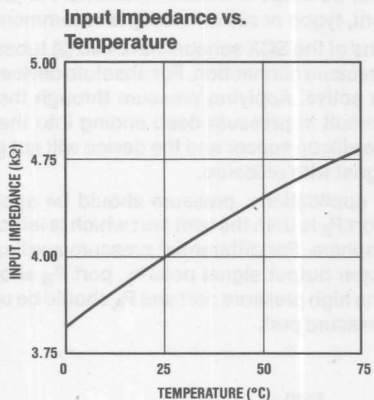
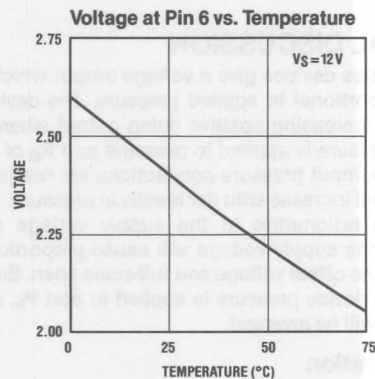
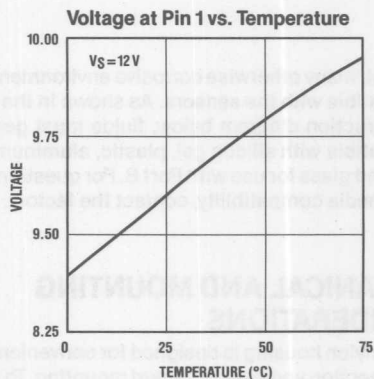
SCX C Series

SCX150C PERFORMANCE CHARACTERISTICS (Note 1)

Characteristic	MIN	TYP	MAX	UNIT
Operating Pressure Range	—	—	150	psi
Sensitivity	—	0.6	—	mV/psi
Full-scale Span (Note 2)	85.0	90.0	95.0	mV
Zero Pressure Offset	-1.0	0	+1.0	mV
Combined Linearity & Hysteresis (Note 3)	—	±0.2	±1.0	%FSO
Temperature Effect on Span (0°C to 70°C) (Note 4)	—	±0.4	±2.0	%FSO
Temperature Effect on Offset (0°C to 70°C) (Note 4)	—	±0.20	±1.0	mV
Repeatability (Note 5)	—	±0.2	±0.5	%FSO
Input Impedance (Note 6)	—	4.0	—	kΩ
Output Impedance (Note 7)	—	4.0	—	kΩ
Common-mode Voltage (Note 8)	5.7	6.0	6.3	V _{DC}
Response Time (Note 9)	—	100	—	μsec
Long Term Stability of Offset and Span (Note 10)	—	±0.1	—	%FSO

TYPICAL PERFORMANCE CHARACTERISTICS

SCX C Series



Specification Notes: (For All Devices)

- Note 1:** Reference Conditions: Unless otherwise noted: Supply Voltage, $V_S = 12\text{ V}_{\text{DC}}$, $T_A = 25^\circ\text{C}$, Common-mode Line Pressure = 0 psig, Pressure Applied to Port B. For absolute devices only, pressure is applied to Port A and the output polarity is reversed.
- Note 2:** Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Span is ratiometric to the supply voltage.
- Note 3:** See Definition of Terms.
Hysteresis — the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
- Note 4:** Maximum error band of the offset voltage and the error band of the span, relative to the 25°C reading.
- Note 5:** Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to $+70^\circ\text{C}$ after:
a) 1,000 temperature cycles, 0°C to $+70^\circ\text{C}$
b) 1.5 million pressure cycles, 0 psi to full-scale span.
- Note 6:** Input impedance is the impedance between pins 2 and 4.
- Note 7:** Output impedance is the impedance between pins 3 and 5.
- Note 8:** This is the common-mode voltage of the output arms (Pins 3 and 5) for $V_S = 12\text{ V}_{\text{DC}}$.
- Note 9:** Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time.
- Note 10:** Long term stability over a one year period.

GENERAL DISCUSSION

The SCX series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port P_B of the device. If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage and full-scale span. Since for absolute device pressure is applied to port P_A , output polarity will be reversed.

User Calibration

The SCX devices are fully calibrated for offset and span and should therefore require little user adjustment in most applications. For precise span and offset adjustments, refer to the applications section herein or contact the Sensym factory.

Vacuum Reference (Absolute Devices)

Absolute sensors have a hermetically sealed vacuum reference chamber. The offset voltage on these units is therefore measured at vacuum, Opsia. Since all pressure is measured relative to a vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

Media Compatibility

SCX devices are compatible with most non-corrosive gases. Because the circuitry is coated with a protective

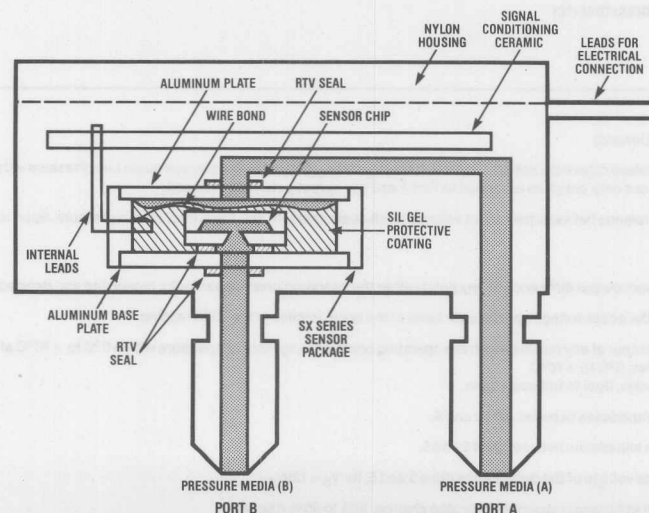
silicon gel, many otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below, fluids must generally be compatible with silicon gel, plastic, aluminum, RTV, silicon, and glass for use with Port B. For questions concerning media compatibility, contact the factory.

MECHANICAL AND MOUNTING CONSIDERATIONS

The SCX nylon housing is designed for convenient pressure connection and easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicon tubing is recommended.

All versions of the SCX sensors have two (2) tubes available for pressure connection. For absolute devices, only port P_A is active. Applying pressure through the other port will result in pressure dead ending into the back-side of the silicon sensor and the device will not give an output signal with pressure.

For gage applications, pressure should be applied to port P_B . Port P_A is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port P_B should be used as the high pressure port and P_A should be used as the low pressure port.



Physical Construction (Cutaway Diagram)

(Not Drawn to Scale)

APPLICATION INFORMATION

Shown here is a popular circuit which gives a high level 2–5V_{DC} output for a 0–10 inch W.C. pressure input. Additional applications circuits are shown in the standard SCX series datasheet and SCX-EB evaluation board literature. For further applications information or assistance, please contact your nearest Sensym sales office or the Sensym factory.

Low Pressure Application

For sensing pressure below 1 psi, the circuit shown in Figure A uses the SCX01DN to provide a 2 to 5V output for a 0 to 10 inch of water column input pressure. This output signal is compatible with many A/D converters and hence can be used to interface to a microprocessor system. This low-cost circuit is easily adaptable to lower full-scale pressure down to 5 inches of water column.

Circuit Description

The LM10 is used to provide a voltage reference for the excitation voltage (V_E), and for the voltage node V_{REF} . With this configuration, V_E and V_{REF} are not affected by noise or voltage variations in the 12V power supply. R_3 is used to adjust V_{REF} to set the initial offset voltage at the output, V_{OUT} .

The pressure signal, V_{IN} , is amplified by amplifiers B_1 and B_2 . (See Sensym Application Note SSAN-17 for details on this amplifier) R_2 is used to adjust the signal gain of the circuit. The output equation is given below.

$$V_{OUT} = V_{IN} \left[2 \left(1 + \frac{R}{R_1} \right) \right] + V_{REF}$$

For the best circuit performance, a careful selection of components is necessary. Use wirebound pots to insure low temperature coefficients and low long-term drift. A five-element resistor array (10k Ω) SIP should be used for the resistors in the amplifier stage in order to obtain closely matched values and temperature coefficients. All other resistors should be 1% metal film. Amplifiers B_1 and B_2 should have low offset voltages and low noise. Signal lines should be as short as possible and the power supply should be capacitively bypassed on the PC board.

Adjustment Procedure

1. With zero-pressure applied, adjust the offset adjust R_3 , until $V_{OUT} = 2.000V$.
2. Apply full-scale pressure (10 in. W.C.) to port B, and adjust the full-scale adjust R_2 , so that $V_{OUT} = 5.000V$.
3. Repeat procedure if necessary.

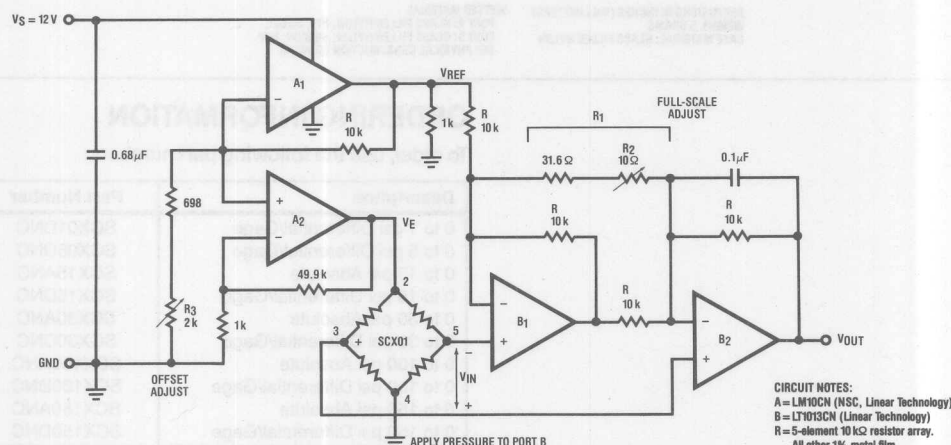
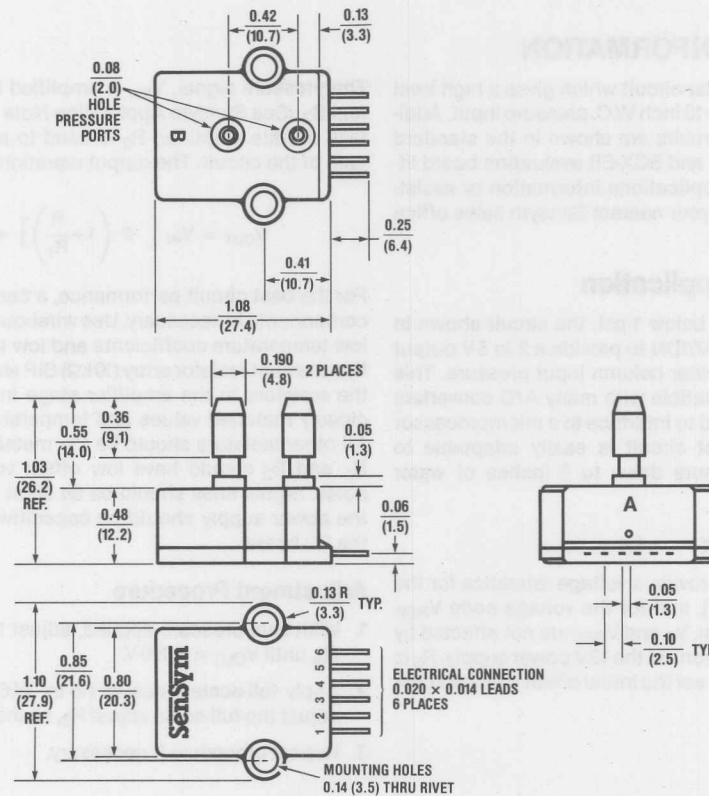


Figure A. Low Pressure Circuits Provide a 2 to 5V Output for a 0–10 in. W.C. Pressure Input.

PHYSICAL DIMENSIONS

SCX C Series



DIMENSIONS IN INCHES (MILLIMETERS)
WEIGHT: 5 GRAMS
CASE MATERIAL: GLASS FILLED NYLON

WETTED MATERIAL
PORT A: GLASS FILLED NYLON, RTV, SILGEL
PORT B: GLASS FILLED NYLON, SILICON, RTV
SEE PHYSICAL CONSTRUCTION DRAWING

ORDERING INFORMATION

To order, use the following part numbers:

Description	Part Number
0 to 1 psi Differential/Gage	SCX01DNC
0 to 5 psi Differential/Gage	SCX05DNC
0 to 15 psi Absolute	SCX15ANC
0 to 15 psi Differential/Gage	SCX15DNC
0 to 30 psi Absolute	SCX30ANC
0 to 30 psi Differential/Gage	SCX30DNC
0 to 100 psi Absolute	SCX100ANC
0 to 100 psi Differential/Gage	SCX100DNC
0 to 150 psi Absolute	SCX150ANC
0 to 150 psi Differential/Gage	SCX150DNC

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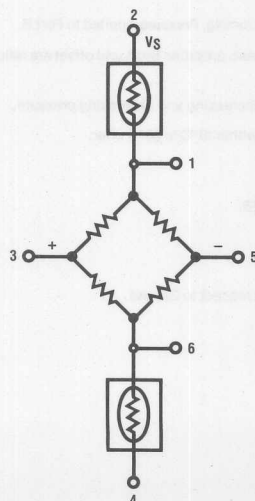
FEATURES

- Precise, Stable, Output
- Temperature Compensated
- Small Size
- Low Noise
- High Impedance for Low Power Portable Applications
- Manufactured in Accordance with GMP for Medical Devices

APPLICATIONS

- Non-Invasive Blood Pressure Monitoring
- Medical Pressure Monitoring

EQUIVALENT CIRCUIT



GENERAL DESCRIPTION

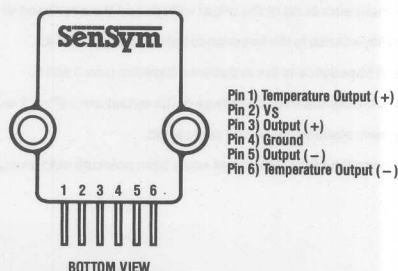
The BP01 sensor was specifically designed for use in medical applications; primarily non-invasive blood pressure monitoring. They provide excellent performance within the pressure range of 0mmHg to 300mmHg and over the temperature range from 10°C to 50°C.

The BP01 consists of a highly linear, low noise semiconductor pressure sensor in combination with a precision thick film ceramic, housed in a compact nylon case. This package offers small size and excellent isolation to external package stresses. It also gives convenient mounting holes and pressure ports for ease of use with standard Tygon* tubing.

The BP01 is internally calibrated and temperature compensated to achieve a high degree of accuracy, stability, and repeatability. Span is calibrated to within $\pm 1\%$ and zero pressure offset is set to ± 300 microvolts maximum. As a result, many applications will not require additional trimming networks in the external signal conditioning circuitry.

The output of the BP01 is ratiometric to the supply voltage and operation from any DC supply voltage up to +30V is acceptable. Because the BP01 is a relatively high impedance circuit (4k Ω), it is also an ideal choice for portable or battery operated equipment. Given its low noise and fast response time, the BP01 provides an excellent choice for many other medical applications.

ELECTRICAL CONNECTION



Note: The polarity indicated is for pressure applied to port B.

*Tygon is a trademark of the Norton company.

PRESSURE SENSOR CHARACTERISTICS

BP01

Maximum Ratings

Supply Voltage, V_S	+30 V _{DC}
Common-mode Pressure	2500 mmHg
Lead Temperature (Soldering, 10 seconds)	300°C
Proof Pressure	1500 mmHg

Environmental Specifications

Temperature Range	+10°C to +50°C
Compensated	0 to +70°C
Operating	–55°C to +125°C
Storage	0 to 100% RH
Humidity Limits	

BP01 PERFORMANCE CHARACTERISTICS (Note 1)

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range	–300	—	300	mmHg
Sensitivity	—	10	—	$\mu\text{V}/\text{V}/\text{mmHg}$
Full-scale Span (Note 2) AT +300 mmHg	14.85	15.0	15.15	mV
Zero Pressure Offset	–6	0	6	mmHg
Linearity 0–200 mmHg	—	—	0.1	%FSO
Linearity 0–300 mmHg	—	—	0.2	%FSO
Hysteresis (Note 3)	—	—	0.05	%FSO
Repeatability (Note 4)	—	—	0.25	%FSO
Temperature Effect on Span (10°C–50°C) (Note 5)	—	—	0.02	%FSO/°C
Temperature Effect on Offset (10°C–50°C) (Note 5)	—	—	0.2	mmHg/°C
Noise (Peak-to-Peak) 0.01 Hz to 10 Hz	—	0.04	—	mmHg
Input Impedance (Note 6)	—	4.0	—	k Ω
Output Impedance (Note 7)	—	4.0	—	k Ω
Common-mode Voltage (Note 8)	2.4	2.5	2.6	V
Long Term Stability of Offset and Span (Note 9)	—	0.1	—	%FSO
Response Time (Note 10)	—	1.0	—	msec

Specification Notes: (For All Devices)

- Note 1:** Unless otherwise noted: Supply Voltage, $V_S = 5.0\text{V}_{\text{DC}}$, $T_A = 25^\circ\text{C}$, Common-mode Line Pressure = 0 mmHg, Pressure Applied to Port B.
- Note 2:** Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Span and offset are ratiometric to the supply voltage.
- Note 3:** Hysteresis — the maximum output difference at any point within the operating pressure range for increasing and decreasing pressure.
- Note 4:** Maximum difference in output at any pressure with the operating pressure range and temperature within 10°C to 50°C after:
a) 1,000 temperature cycles, 10°C to 50°C
b) 1.5 million pressure cycles, 0 psi to full-scale span.
- Note 5:** Maximum error band of the offset voltage and the error band of the span, relative to the 25°C reading.
- Note 6:** Input impedance is the impedance between pins 2 and 4.
- Note 7:** Output impedance is the impedance between pins 3 and 5.
- Note 8:** This is the common-mode voltage of the output arms (Pins 3 and 5) for $V_S = 5.0\text{V}_{\text{DC}}$. Measured with respect to Ground.
- Note 9:** Long term stability over a one year period.
- Note 10:** Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time.

GENERAL DISCUSSION

Output Characteristics

The BP01 provides a voltage output which is directly proportional to applied pressure. The devices will give a positive going output when increasing pressure is applied to pressure Port B of the device (See Figure I). If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage and full-scale span. For medical applications that require true differential pressure, Port B should be used as the high pressure port and Port A should be used as the low pressure port.

User Calibration

The BP01 is fully calibrated for offset and span and should therefore require little if any user adjustment in most applications. For precise span and offset adjustments, refer to the applications section herein or contact the Sensym factory.

MECHANICAL AND MOUNTING CONSIDERATIONS

The BP01 nylon housing is designed for convenient pressure connection and easy PC board mounting. The simplest PC board mounting technique is to use "xmas tree" clips as fasteners (Sensym Part #SCXCLIP), this technique is illustrated in Figure II. The xmas tree clip secures the BP01 to the board with minimum package stress. For electrical connections, we recommend a standard 6 pin right angle connector (Sensym Part #SCXCNCT). In blood pressure applications flexible Tygon or silicon tubing is suggested for pressure connection as it is easy to work with and quite pliable so package stresses are minimized. To secure the tubing

properly to either port Sensym offers a standard easy to use hose clamp (Sensym Part #SCXSNP1).

For further information regarding mounting, refer to Sensym's application note SSAN-25.

Media Compatibility

The sensor is only recommended for use with air media for non-invasive blood pressure measurement.

The BP01 is not sterilized, therefore it is prohibited to bring blood or saline solution into direct contact with the sensor.

APPLICATION INFORMATION

Introduction

The following application information gives circuit ideas for some of the more common applications of the BP01. Please note however that Sensym cannot be an expert in any given application and although we provide application assistance on Sensym products both verbally and through our literature, it is still the total responsibility of the customer to determine the suitability of any product used in their application. For components suggested in any application information, it is also the responsibility of the customer to check with the individual component manufacturers for suitability of these products in the given application.

For additional application information, refer to Sensym's SCX series datasheet or contact the factory directly.

General

The circuit shown in Figure A provides a 0.5V to 3.5V output for a 0 to 300 mmHg input pressure. The circuit is easily calibrated and is not affected by changes in the supply voltage.

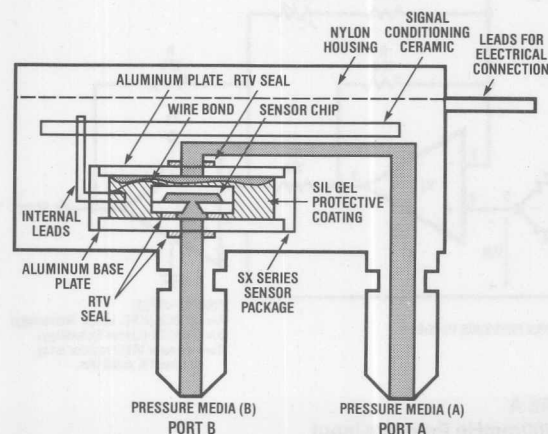


FIGURE I
SCX Physical Construction Diagram (Cutaway View)

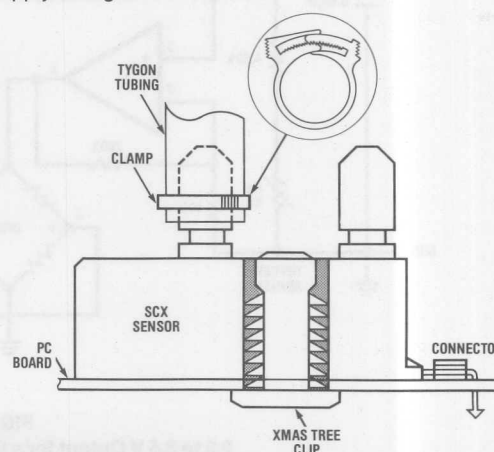


FIGURE II
Recommended PC Board Mounting
Technique for the SCX Sensor

APPLICATION INFORMATION (Cont.)

Circuit Description

The LM10 (A_1) has a precision 200mV reference present at Pin 8 which is amplified by A_2 to provide an excitation (V_E) of 4.2 volts to the top of the BP01 sensor. By providing a buffered reference voltage to the sensor, the circuit becomes insensitive to power supply variations and will operate from 5 volts to 20 volts without performance degradation. The same 200mV reference is also amplified to provide voltage V_{REF} , which is adjusted by means of R_3 to set the initial 0.5 volt output voltage when there is no pressure applied.

From the BP01 specifications, it is noted that at 300mmHg applied pressure, the output of the BP01 will nominally be 15 mV when using a 5 volt supply. Because the output is ratiometric to the supply voltage, the expected output for a supply of 4.2 volts will be 12.6mV. The required gain can now be calculated. Since the output span required is 3 volts (3.5 volts minus 0.5 volts), and the input to the amplifier will be 12.6mV, the gain required from amplifier configuration B_1 and B_2 is 238 V/V.

The output voltage equation (Eq. 1) and the gain equation derived (Eq. 3) are given below and are now used to solve for the unknown resistance, R_T .

$$V_{OUT} = V_{IN} \left[2 \left(1 + \frac{R}{R_T} \right) \right] + V_0 \quad (1)$$

or rewriting

$$V_{OUT} = V_{IN} A_V + V_0 \quad (2)$$

$$\text{where } A_V = \frac{\Delta V_{OUT}}{\Delta V_{IN}} = 2 \left(1 + \frac{R}{R_T} \right) \quad (3)$$

and V_0 = initial output V_{OUT} for zero pressure applied.

With $R = 10k$, R_T is found to be 85Ω . To allow for component tolerances in the gain adjustment, R_T consists of a 1% metal film 75Ω resistor in series with a 20Ω multturn cermet trim pot.

Adjustment Procedure

1. With zero-pressure applied, adjust the offset adjust R_3 until $V_{OUT} = 0.500$ V.
2. Apply full-scale pressure (300mmHg) to Port B, and adjust R_2 until $V_{OUT} = 3.500$ V.
3. Repeat procedure if necessary.

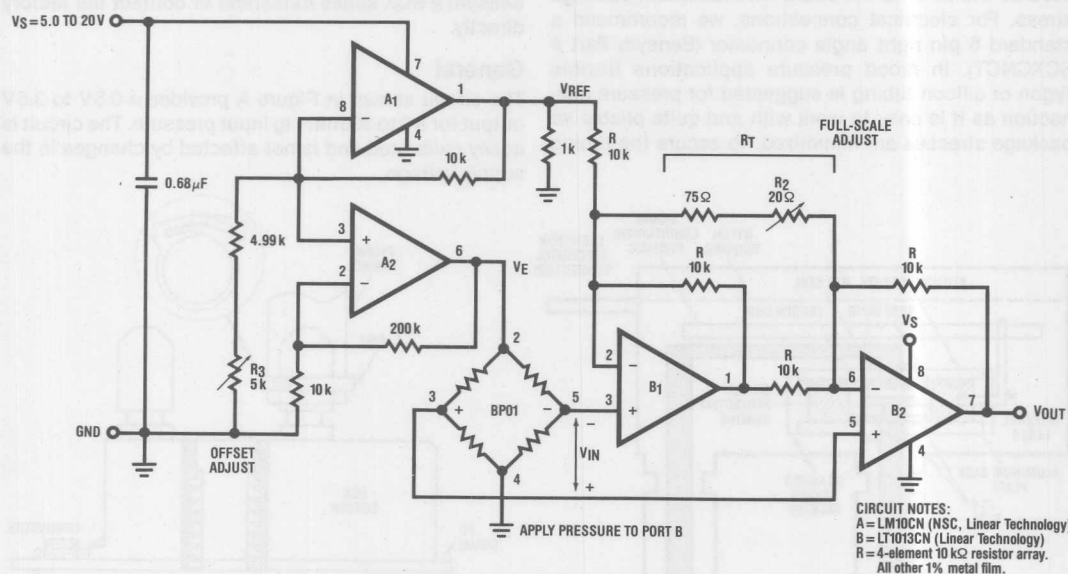


FIGURE A
0.5 to 3.5 V Output for a 0-300 mmHg Pressure Input

APPLICATION INFORMATION (Cont.)

0V to 5V Output

The circuit shown in Figure B is similar to that shown in Figure A, except, it provides a true 0 to 5V output, for a 0 to 300 mmHg pressure input.

Circuit Description

In order to achieve an output voltage that will truly swing to zero volts (or even slightly below ground), a negative supply must be used. The circuit shown below makes use of a popular power supply inverter, the LTC1044, to achieve a negative supply voltage of -1.23 V ($-V$) using a single supply of 12V and ground. The LTC1044 can be used in this application because the BP01 and the circuitry shown requires less than 5mA of current.

The negative 1.23 V ($-V$) is used to power the amplifiers as well as a negative voltage for the zero adjust divider network. In this manner, the offset pot (R_0) adjusts V_{REF} to compensate for offset errors in the op amp circuitry and sensor, and enables the output to be set to 0.00 volts with zero pressure applied.

The 2.5V reference, Z1, is amplified by A1 to provide a 10V excitation voltage (V_E) to the BP01. Since the output voltage of the BP01 is ratiometric to its supply, the sensor output will now be 30mV for a 300mmHg full scale pressure applied.

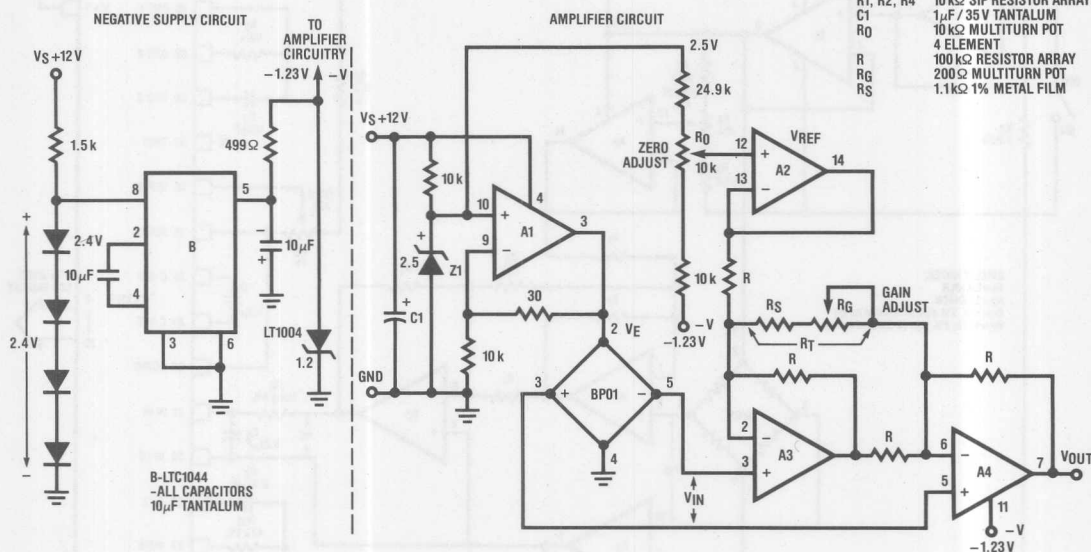


FIGURE B

True 0 to 5 V Output for 0-300 mmHg Pressure Input using a Single +12V Supply and Ground

BP01

PORTABLE PRESSURE METER

General

The circuit shown in Figure C is a 0 to 200 mmHg portable pressure meter. The $3\frac{1}{2}$ digit display will read 199.9 mmHg full-scale. This circuit operates from a single 9V battery and draws approximately 4.5 mA supply current, thus providing a typical battery life in excess of 100 hours. The minimum battery voltage is approximately 6.5V.

This meter provides a resolution of 0.1 mmHg. The same circuit can also be used for other pressure ranges simply by changing the sensor and gain.

Circuit Description

The LM10 provides a 200 mV reference on pin 8 (A_1) which is amplified ($A_V = 1 + R_2/R_3$) and buffered to provide a stable +5V supply for the circuit. The resistor divider network comprised of two 100 k resistors and pot R_4 provide the offset adjustment for the circuit. Since the BP01 provides an output which is ratiometric to its supply voltage, using the data sheet electrical specifications, the expected output voltage will be 10 mV at 200 mmHg when operating from a 5 volt supply. For the component values shown, a full-scale input voltage of 200 mV (V_0) is required to the ICL7106 in order

to display a full scale output of 1999, thus the gain required for the instrumentation amplifier is 20 V/V. Again, from the gain equation (Eq. 3) with $R_1 = 10$ k, R_7 is found to be 1.1 k. In this circuit, a fixed 1% metal film resistor has been used for R_7 . The fine tuning of the full scale span adjustment is accomplished by using Pot R_8 , which sets the reference voltage of the A/D converter.

Component Selection

The value of the components R_6 – R_{10} and C_1 – C_5 have been optimized for 200 mV full-scale. (See the Intersil ICL7106 Datasheet). R_4 and R_8 should be 15 turn cermet pots, R_6 – R_{10} are metal film 1% resistors. C_3 the integrating capacitor should be polypropylene, the reference and auto zero capacitors can be polystyrene or mylar, the clock capacitor, C_4 , is mica.

Adjustment Procedure

Apply 165 mmHg and adjust R_8 until the display reads 165. Apply 0 mmHg and adjust R_4 until the display reads 000.0. Repeat if required.

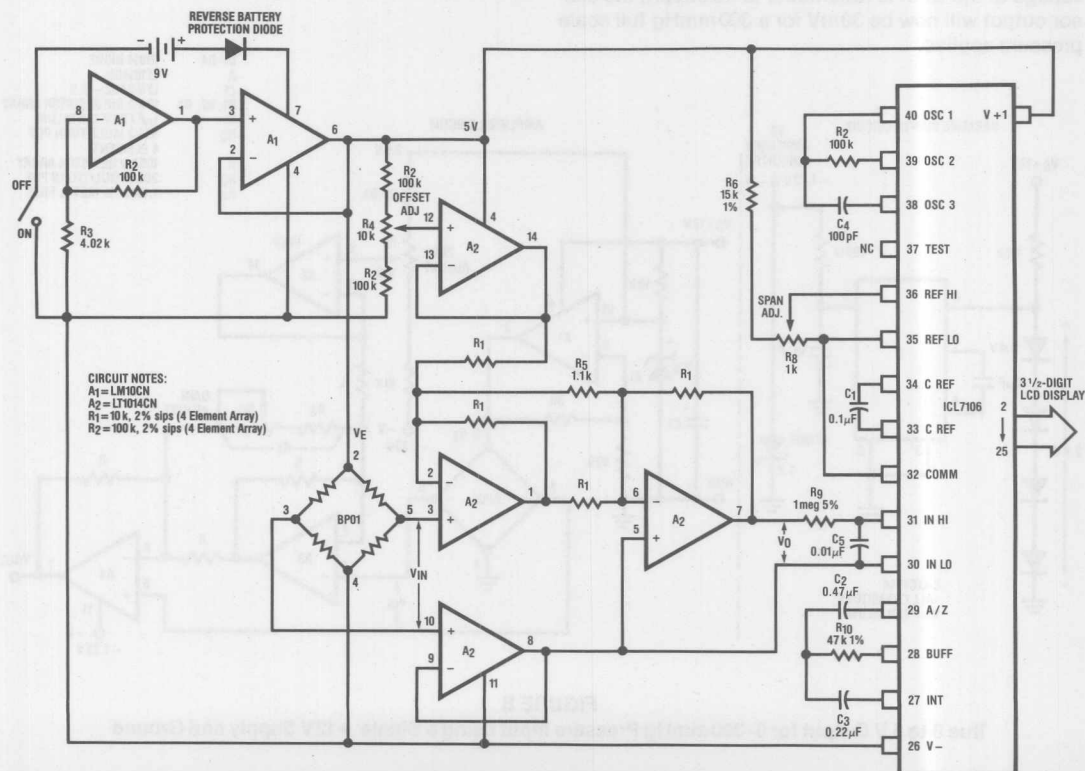


FIGURE C
0-200 mmHg Meter

PARALLEL A/D CONVERSION

BP01

General

The BP01 sensor can be easily interfaced to a microprocessor bus. Using an A/D converter, for a 0 to 300mmHg input, the circuit in Figure D will provide an eight-bit parallel output which is proportional to applied pressure. The circuit allows for easy calibration and uses a single 5V supply.

Circuit Description

The LM10 provides both the reference voltage V_{REF} and the sensor excitation voltage V_E which are independent of supply voltage changes above the 5V supply. V_{REF} is amplified by B_3 to provide the A/D converter with 1.5 volt reference voltage. With a 1.5 volt reference, a full-scale output of all "ONES" will occur when the input signal to the A/D is 3 volts.

The sensor excitation voltage V_E of 4.2V will result in a differential sensor output of 12.6mV when an input pressure of 300mmHg is applied. This output signal is amplified by B_1 and B_2 to provide the converter with $V_{IN}(+)$. The gain is adjusted using pot R_G . The initial offset

voltage is adjusted by R_3 , which varies $V_{IN}(-)$ on the converter. The A/D converter, as shown, is a free-running configuration and the binary output is updated continuously.* The only requirement is that the $\overline{WR}$ and $\overline{INTR}$ must be momentarily grounded or taken to a logic low after power-up to ensure proper operation.

Adjustment Procedure

1. With no pressure applied, adjust the offset pot R_3 until all bits are zero except the LSB, which should be switching between one and zero.
2. Apply full-scale pressure (1 psig) to Port B, and adjust the full-scale pot R_G until all bits are ones except the LSB which should be flickering between one and zero.
3. Repeat procedure if necessary.

*For timing specifications and bus interface, see the ADC0804 Datasheet from National Semiconductor.

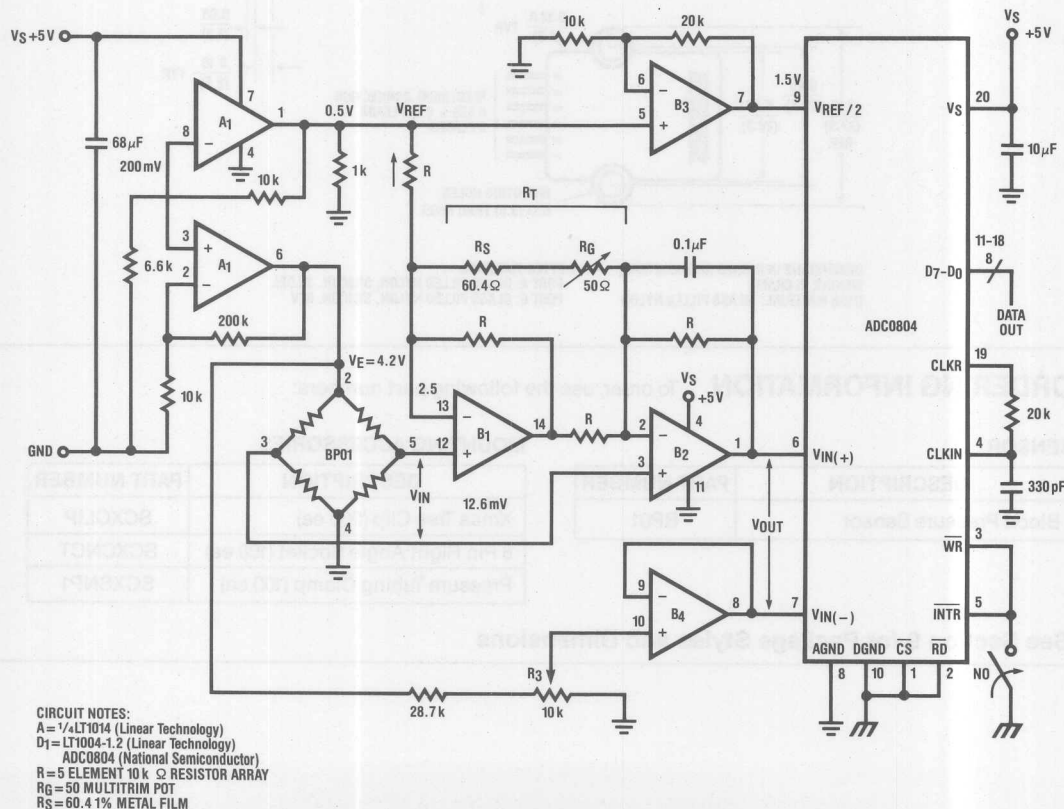
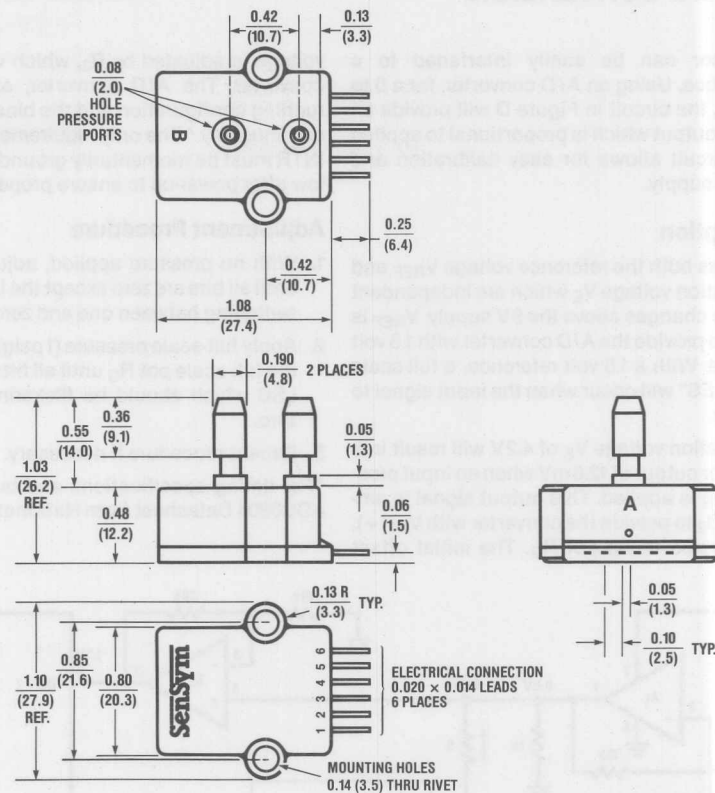


FIGURE D
A Parallel A/D Conversion Circuit for 0-300mmHg Applications

PHYSICAL DIMENSIONS

BP01



DIMENSIONS IN INCHES (MILLIMETERS)
WEIGHT: 5 GRAMS
CASE MATERIAL: GLASS FILLED NYLON

WETTED MATERIAL
PORT A: GLASS FILLED NYLON, SILICON, SILGEL
PORT B: GLASS FILLED NYLON, SILICON, RTV

ORDERING INFORMATION

To order, use the following part numbers:

SENSOR

DESCRIPTION	PART NUMBER
Blood Pressure Sensor	BP01

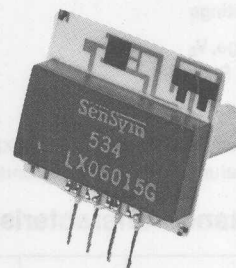
MOUNTING ACCESSORIES

DESCRIPTION	PART NUMBER
Xmas Tree Clip (200 ea)	SCXCLIP
6 Pin Right Angle Socket (100 ea)	SCXCNCT
Pressure Tubing Clamp (100 ea)	SCXSNP1

See Section 9 for Package Styles and Dimensions

Sensym

LX06XXXG, LX06XXXD, and LX06XXXA Series Temperature Compensated Monolithic Pressure Transducers



General Description

The monolithic pressure transducers are piezoresistive integrated circuits which provide an output voltage proportional to applied pressure. The devices are provided in compact packages with pressure ports, suitable for PC board mounting and attachment of flexible tubing.

The LX06XXXG is a gage transducer with a single tube and an ambient inlet. It is well suited for use with package-compatible working fluids, including water.

The LX06XXXD is a differential pressure transducer with 2 pressure ports, suitable for use with non-ionic working fluids in either pressure port, and package-compatible working fluids in the positive pressure port.

The LX06XXXA is an absolute pressure transducer with a single tube pressure port, suitable for use with non-ionic working fluids.

See Application Guide—Media Compatibility.

ADVANTAGES OF MONOLITHIC

The monolithic transducers include only the basic monolithic pressure IC chip used in Sensym's signal-conditioned pressure transducer products. This greatly reduces unit cost and allows the electronic designer greater freedom in implementing transducer circuits.

Calibrated sensitivity, a calibrated offset and low noise allow easy amplification. These devices are especially useful in applications requiring battery power, circuit flexibility, or compatibility with microprocessors.

TEMPERATURE COMPENSATION

All LX06XXX series transducers have thick film thermistor temperature compensation external to the sensor element. This compensation is equally distributed above and

below the bridge so as to maintain a consistent common-mode voltage across the bridge, thereby decreasing common-mode signal errors. The temperature compensated is linearized and matched to each sensor using advanced laser trimming techniques.

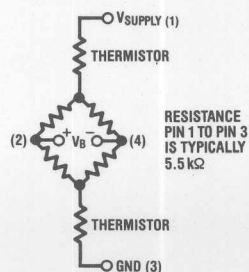
Features

- Low cost
- Low noise
- Temperature compensated
- Wide operating temperature range
- Small size and light weight
- High natural frequency
- Low volumetric displacement
- Alternate source available
- Vibration and shock insensitive
- Ratiometric output voltage
- Offset and sensitivity calibrated
- Compact package suitable for PC board mounting

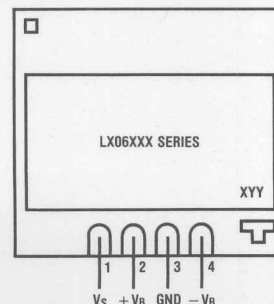
Applications

- Medical diagnostics
- Automotive diagnostics and controls
- Barometry
- Computer peripherals, control and diagnostics

Schematic Diagram



Electrical Connection



Pressure Transducer Characteristics

Maximum Ratings

Supply Voltage, V_S	16 V
Temperature Range	
Operating	-40°C to +125°C
Storage	-55°C to +125°C
Common-Mode Line Pressure, LX06XXXD	100 psid
Lead Temperature (Soldering, 10 seconds)	200°C

Reference Conditions (Note 1)

Supply Voltage, V_S	10 V
Reference Temperature	25°C
Common-Mode Line Pressure, LX06XXXD	0 psid

Performance Characteristics

Device Type	Operating Pressure Range	Maximum Over Pressure	Offset Calibration			Sensitivity	Linearity (Note 2)	Repeatability and Hysterisls	Offset Shift with Temperature (0 to 50°C)	Sensitivity Shift with Temperature (0 to 50°C)	Full Scale Output Calibration (Note 3)		
			mV								mV/psi	%FS	%FS
			Min.	Typ.	Max.	Typ.	Typ.	Typ.	Typ.	Typ.	Typ.	Min.	Typ.
LX06001G	0 to ±1psig	20psig	−2	0	+2	27.7	±1.5	0.10	±2	±1.5	25.5	28	30.5
LX06001D	±1psid	20psid	−2	0	+2	27.7	±1.5	0.10	±2	±1.5	25.5	28	30.5
LX06002G	0 to ±2psig	20psig	−2	0	+2	20.0	±1.5	0.10	±2	±1.5	38.5	40	41.5
LX06002D	±2psid	20psid	−2	0	+2	20.0	±1.5	0.10	±2	±1.5	38.5	40	41.5
LX06005G	0 to ±5psig	20psig	−1	0	+1	10.0	±1.5	0.10	±2	±1.5	48.5	50	51.5
LX06005D	±5psid	20psid	−1	0	+1	10.0	±1.5	0.10	±2	±1.5	48.5	50	51.5
LX06015A	0 to 15psia	40psia	−2	0	+2	−6.67	±1.0	0.10	±2	±1.5	−97.5	−100	−102.5
LX06015G	0 to ±15psig	40psig	−1	0	+1	6.67	±1.0	0.10	±2	±1.5	98.5	100	101.5
LX06015D	±15psid	40psid	−1	0	+1	6.67	±1.0	0.10	±2	±1.5	98.5	100	101.5
LX06030A	0 to 30psia	60psia	−2	0	+2	−2.63	±0.50	0.10	±2	±1.5	−74	−79	−84
LX06030G	0 to 30psig	60psig	−1	0	+1	2.63	±0.50	0.10	±2	±1.5	75	79	83
LX06030D	±30psid	60psid	−1	0	+1	2.63	±0.50	0.10	±2	±1.5	75	79	83
LX06100A	0 to 100psia	200psia	−1	0	+1	−1.4	±0.50	0.10	±2	±1.5	−136	−140	−144
LX06100G	0 to ±100psig	200psig	−1	0	+1	1.4	±0.50	0.10	±2	±1.5	136	140	144

Specification Notes:

Note 1: Conditions at which device "Performance Characteristics" apply.

Note 2: Linearity—the maximum deviation of measured output, at constant temperature (25°C), from "best straight line" through three points (offset pressure, full scale pressure, one-half full scale pressure).

$$\% \text{ FS error} = \frac{V_{1/2 \text{ full scale}} - \left\{ \left(\frac{V_{\text{full scale}} - V_{\text{offset}}}{\text{full scale pressure}} \right) \times \left(\frac{1}{2} \text{ full scale pressure} \right) + V_{\text{offset}} \right\}}{2(V_{\text{full scale}})} \times 100\%$$

(V = measured value for each device)

Note 3: Full-scale is the algebraic difference between endpoints. Where one endpoint is actual offset voltage and the other endpoint is the upper limit of the range.

TESTING

All guaranteed parameters are tested on multiple occasions in production and are assured in conformance to specification by outgoing quality assurance inspection. A Mensor pressure reference is used as a calibrated pressure reference source. All voltage readings are verified by a 4½-digit calibrated voltmeter. Non-guaranteed parameters are characterized during initial product characterization and reflect the performance of the product at that time. To guarantee any of these parameters requires a request for special product. Consult your Sensym distributor or representative for details.

Application Guide

MEDIA COMPATIBILITY—HUMIDITY

The heart of the transducer is a monolithic silicon chip with a cavity etched out to form a diaphragm. The top side of the diaphragm contains the transducer pressure sensing circuitry.

Absolute pressure devices (LX06XXXXA) have a brass tube on the negative pressure inlet port only. The sensor cavity is a vacuum reference and the positive pressure port is sealed closed. A silicone gel material covers the sensor and provides immunity to high humidity environments. However, this material does not provide long term protection against water, other aqueous fluids, nor ionic fluids.

Gage pressure devices (LX06XXXG) have a brass tube on the positive pressure inlet port only. Ambient pressure is the reference pressure and is applied through a vent hole

in the ceramic substrate. A silicone gel material covers the sensor and provides immunity to high humidity environments. The working fluid is applied through the positive pressure port and must be compatible with brass, ceramic, silicon, and polyimide. Silicon is at the same voltage potential as the supply voltage. Therefore the fluid must be electrically non-conductive or electrically isolated from the supply voltage.

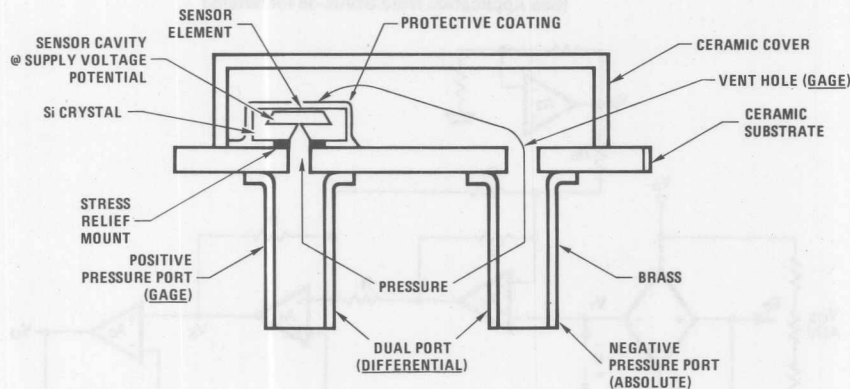
Differential pressure devices (LX06XXXD) have two brass tubes, one on each pressure port. Fluids applied to the negative pressure port must conform to conditions specified for absolute pressure devices. Fluids applied to the positive pressure port must conform to conditions specified for gage pressure devices.

PACKAGE LEAK RATE

The PX6 package is not hermetic. Sensym's pressure transducers are guaranteed to have an effective leak area less than 10^{-7} cm². Each transducer is leak tested at room temperature with 45 psig compressed air. However, the user should be aware that the leak rate can depend on the type, viscosity, pressure, and temperature of the working fluid and can increase with fatigue resulting from pressure cycling. This is especially important in static systems where a fluid under pressure is to be maintained for an extended period in an enclosure without replenishment. This leak rate applies to package leak rate and not the reference chamber in absolute (A) devices which is hermetic.

SIGNAL AMPLIFICATION

Figures 1 and 2 show the LX06XXX series in use with some simple amplifier schemes. These circuits are described fully in application notes SSAN-17 and SSAN-18.



LX06XXX Pressure Transducer Structure

Application Guide (Continued)

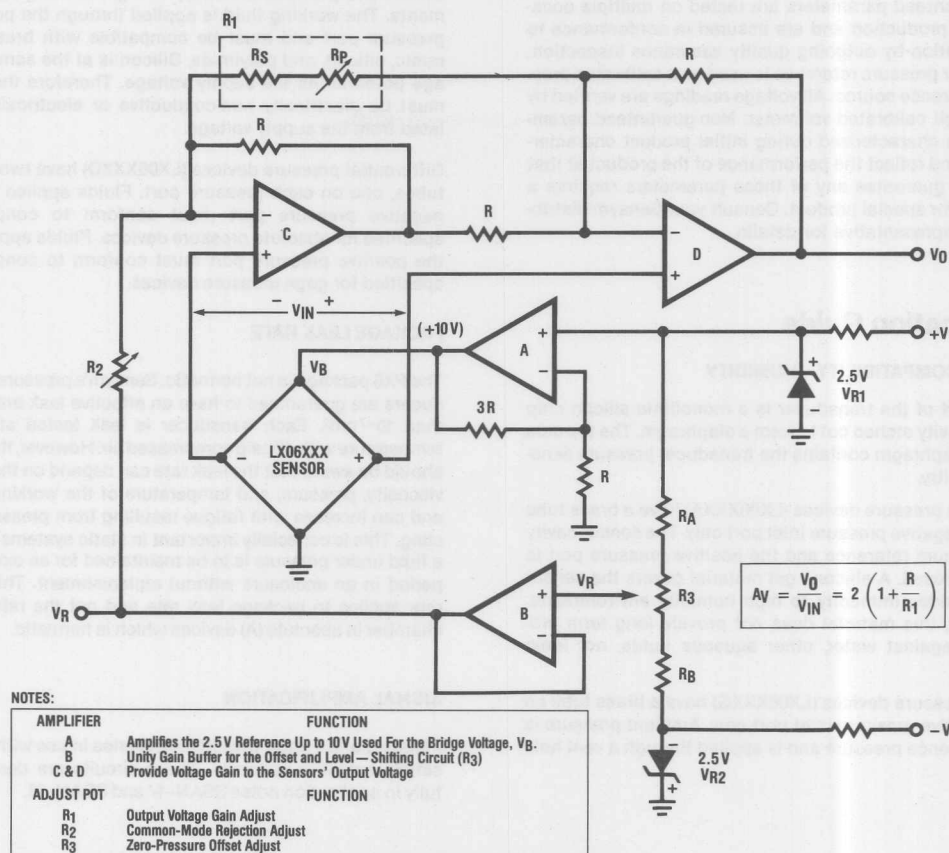


FIGURE 1. Amplified Output Using Dual Supplies
(See Application Note SSAN-18 for details)

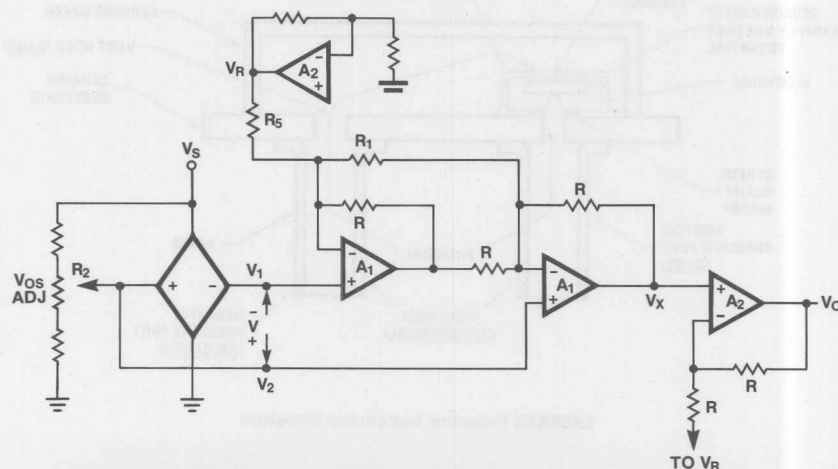


FIGURE 2. Amplified Output Using A Single Supply
(See Application Note SSAN-17 for details)

Application Guide (Continued)

SINGLE SUPPLY, RATIOMETRIC, RAIL-TO-RAIL SIGNAL CONDITIONING CIRCUIT

Typically this circuit is employed in single supply 5V systems in conjunction with a ratiometric analog-to-digital converter (ADC0801 series). It could just as easily be incorporated into any fixed voltage system.

Circuit Description

In Figure 3, a sensor is used with one NSC LM324 and one NSC LM10. The NSC LM10 reference is used to minimize common-mode voltage error across the first stage differential input. The voltage at V2 is set to one-half the supply voltage. This is the same voltage as pins 2 and 4 of the sensor with an unstrained bridge.

$$V_2 = V_R + V_R \frac{R_{10}}{R_9}$$

With R1 equal to R4 and R3 equal to R2 and a change in voltage of ΔV_B across the bridge results in

$$V_1 = \Delta V_B \left(1 + \frac{R_1}{R_2} \right) + V_2$$

R8 and R7 are used to set the offset voltage. At offset conditions, these resistors are adjusted for the desired offset voltage. For zero output voltage, typically R7 = 40 Ω and R8 = 400 Ω and are adjusted so that the NSC LM10 is on the threshold of saturation at offset conditions.

i.e., for $V_S = 5V$ and $R_5 = 4k$,

$R_6 = 40k$ (output stage gain of 10) at offset

$V_2 = 2.5V$, set $V_O = 0V$

$$V_3 = 2.5 - \frac{2.5}{10} = 2.27V$$

The gain of this amplifier is equal to the gain of the first stage times the output stage gain

$$V_O = -(V_1 - V_3) \frac{R_6}{R_5} + V_3$$

For LX06015G and 0V to 5V operation, this requires a total gain of 50.

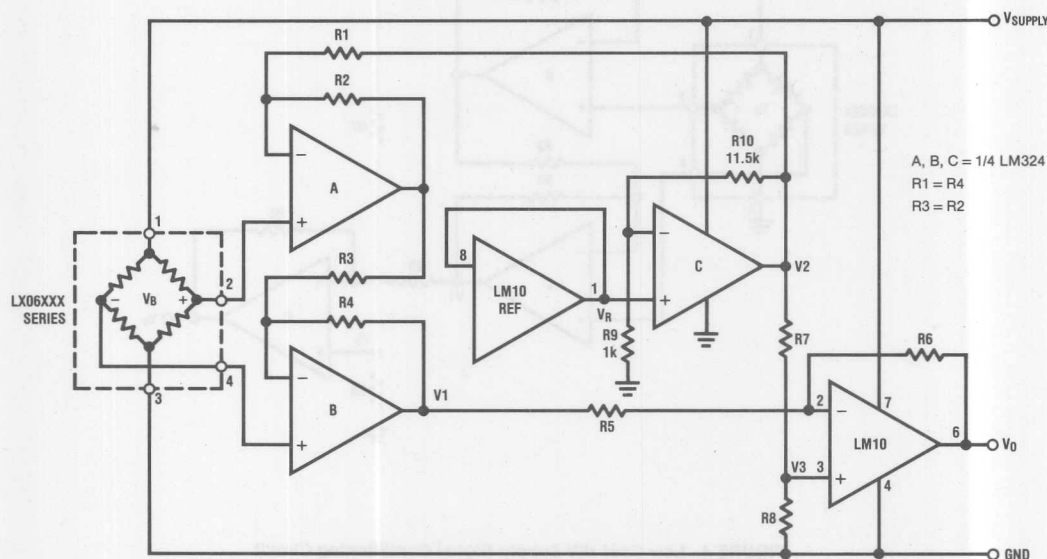


FIGURE 3. Single Supply, Ratiometric, Rail-to-Rail Signal Conditioning Circuit
(for absolute devices pins 2 and 4 are reversed)

Application Guide (Continued)

LOW COST 15V SUPPLY SIGNAL CONDITIONING CIRCUIT (Figure 4)

The LH0070 is a precision 10.00V reference. All aspects of this circuit follow the details as described for the single supply, ratiometric, rail-to-rail signal conditioning circuit previously.

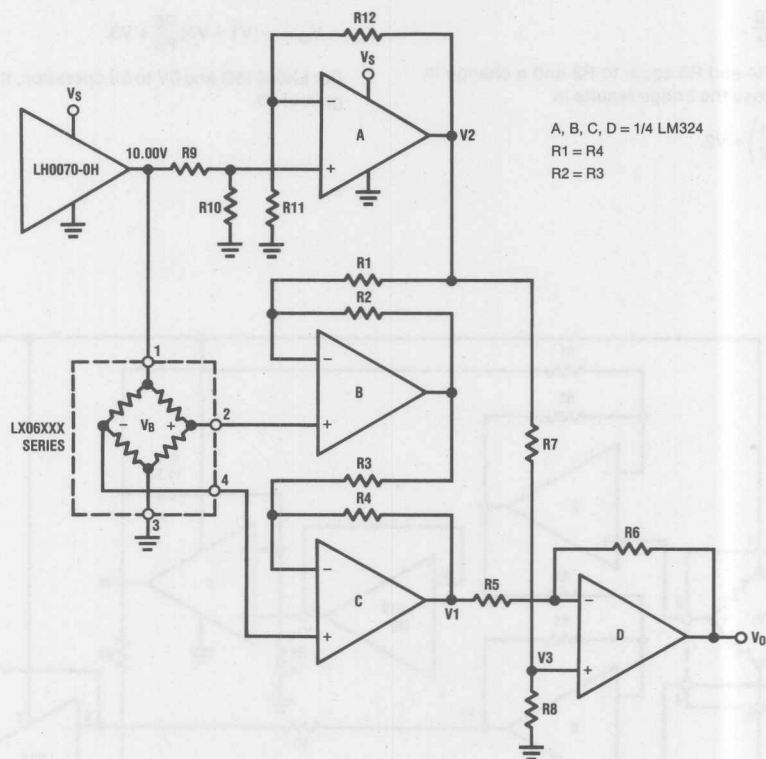


FIGURE 4. Low Cost 15V Supply Signal Conditioning Circuit

Application Guide (Continued)

SECOND SOURCE

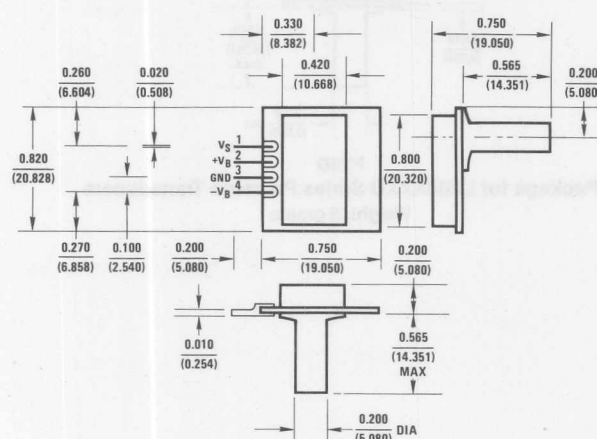
As a second source, the Honeywell/Microswitch 126 and 136 series parts are pin-for-pin equivalent to the LX06XXX series. There is one difference in the two products. The common-mode voltage upon which the output voltage changes is typically one-half the supply voltage for

Sensym's products; for Honeywell devices this is typically one-third the supply voltage. For Sensym's products this allows full use of the pressure rating symmetrically around this voltage. See Typical Physical Dimensions section for pressure port locations.

Sensym Part #	Honeywell Part #	Sensitivity @10V (mV/psi)	Maximum Calibrated Pressure
LX06001G		27.7	1psig
LX06001D		27.7	1psid
LX06002G		20	2psig
LX06002D		20	2psid
LX06005G	126PC05G1, 136PC05G1	10	5psig
LX06005D	126PC05D1	10	5psid
LX06015A	126PC15A1, 136PC15A1	-6.67	15psia
LX06015G	126PC15G1	6.67	15psig
LX06015D	126PC15D1	6.67	15psid
LX06030A	126PC30A1, 136PC30A1	-2.63	30psia
LX06030G	126PC30G1, 136PC30G1	2.63	30psig
LX06030D	126PC30D1	2.63	30psid
LX06100G		1.4	100psig

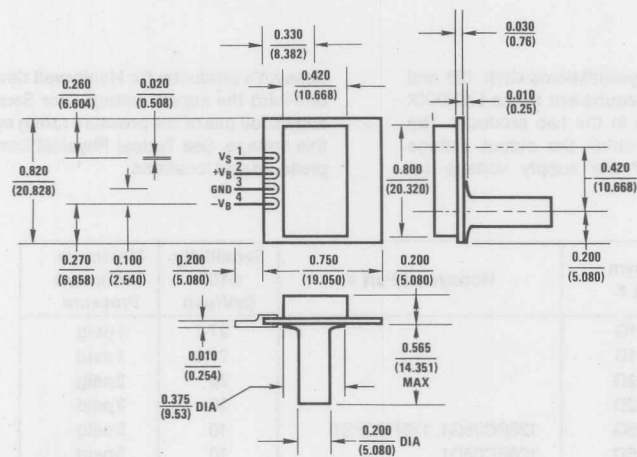
*Linearity is typically 0.25% full-scale.

Typical Physical Dimensions inches (millimeters) for reference only

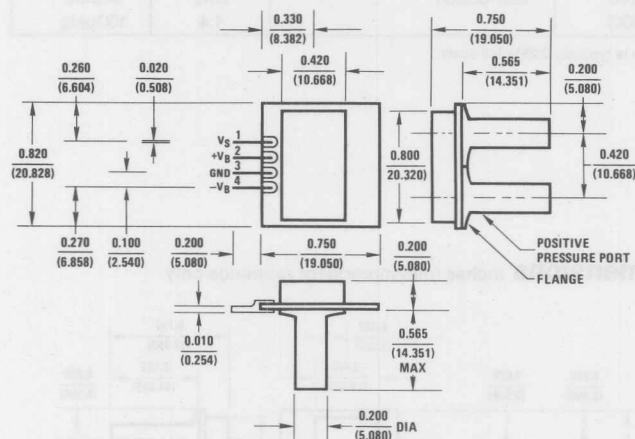


PX6A
Package for LX06XXXA Series Pressure Transducers
Weight: 5 grams

Typical Physical Dimensions (Continued) inches (millimeters) for reference only



PX6B
Package for LX06XXXG Series Pressure Transducers
Weight: 5 grams



PX6D
Package for LX06XXXD Series Pressure Transducers
Weight: 5 grams

SenSym

SOLID STATE SENSORS

SCXL004DN

0 - 4 In. H₂O

PRECISION COMPENSATED, LOW PRESSURE, SENSORS

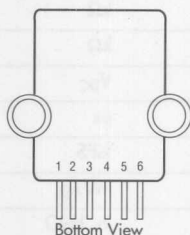
FEATURES

- Very Low Pressure Resolution
- Precision Temperature Compensation
- Small Size
- Low Noise
- Calibrated Zero and Span
- High Impedance for Low Power Applications

APPLICATIONS

- Air Flow
- Respirators
- HVAC

ELECTRICAL CONNECTIONS



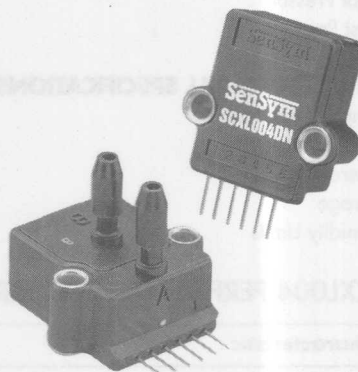
- Pin 1. Temperature Output (+)
- Pin 2. V_S
- Pin 3. Output (+)
- Pin 4. Ground
- Pin 5. Output (-)
- Pin 6. Temperature Output (-)

Note: The polarity indicated is for pressure applied to port B

GENERAL DESCRIPTION

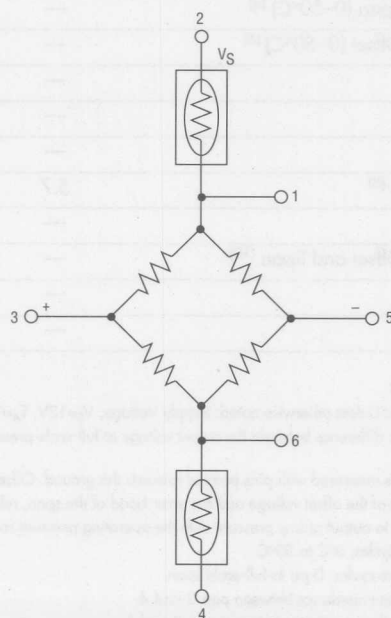
The SCXL series sensors provide a very cost effective solution for pressure applications that require high accuracy over very low operating pressure ranges. These internally calibrated and temperature compensated sensors were specifically designed to provide an accurate and stable output over a 0°C to 50°C temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases, and the like.

The output of the bridge is ratiometric to the supply voltage and operation from any D.C. supply voltage up to +18V is acceptable.



2

EQUIVALENT CIRCUIT



PRESSURE SENSOR CHARACTERISTICS

MAXIMUM RATINGS

Supply Voltage, V_S	+18V _{DC}
Common-mode Pressure	150 In. H ₂ O
Lead Temperature	300°C
(Soldering, 10 seconds)	10 In. H ₂ O
Proof Pressure	5 psi
Burst Pressure	

WARNING:

Due to the delicate nature of these very sensitive devices, some special handling is required. Parts are sensitive to shock and vibration and must be handled with care. Dropping on any hard surface (bench top etc.) can destroy the device. Note 10 In. H₂O max overpressure.

ENVIRONMENTAL SPECIFICATIONS

Temperature Range	0 to 50°C
Compensated	0°C to +70°C
Operating	0°C to +70°C
Storage	0 to 80% RH
Humidity Limits	

SCXL004 PERFORMANCE CHARACTERISTICS ⁽¹⁾

Characteristic	Min.	Typ.	Max.	Unit
Operating Pressure Range	—	—	4	In. H ₂ O
Sensitivity	—	10	—	mV/In. H ₂ O
Full-scale Span ⁽²⁾	38	40	42	mV
Zero Pressure Offset	-1.5	0	+1.5	mV
Combined Linearity and Hysteresis ⁽³⁾	—	±0.5	±1.0	%FS
Temperature Effect on Span (0–50°C) ⁽⁴⁾	—	±0.5	±2.0	%FS
Temperature Effect on Offset (0–50°C) ⁽⁴⁾	—	±0.50	±1.5	mV
Repeatability ⁽⁵⁾	—	±0.2	—	%FS
Input Impedance ⁽⁶⁾	—	4.0	—	kΩ
Output Impedance ⁽⁷⁾	—	4.0	—	kΩ
Common-mode Voltage ⁽⁸⁾	5.7	6.0	6.3	V _{DC}
Response Time ⁽⁹⁾	—	500	—	μs
Long Term Stability of Offset and Span ⁽¹⁰⁾	—	±0.5	—	%FS
Position Sensitivity	—	0.25	—	mV/g
Proof Pressure ⁽¹¹⁾	—	10	—	In. H ₂ O

SPECIFICATION NOTES:

- Note 1: Reference Conditions: Unless otherwise noted: Supply Voltage, $V_S=12V$, $T_A=25^\circ C$, Common-mode Line Pressure=0 psig, Pressure Applied to Port B.
- Note 2: Span is the algebraic difference between the output voltage at full-scale pressure and the output at zero pressure. Span is ratiometric to the supply voltage.
- Note 3: Zero pressure effect is measured with pins pointed towards the ground. Offset can be position sensitive.
- Note 4: Maximum error band of the offset voltage and the error band of the span, relative to the 25°C reading.
- Note 5: Maximum difference in output at any pressure with the operating pressure range and temperature within 0°C to +50°C after:
- 100 temperature cycles, 0°C to 50°C
 - 1.0 million pressure cycles, 0 psi to full-scale span.
- Note 6: Input impedance is the impedance between pins 2 and 4.
- Note 7: Output impedance is the impedance between pins 3 and 5.
- Note 8: This is the common-mode voltage of the output arms (Pins 3 and 5) for $V_S=12V$.
- Note 9: Response time for a 0 psi to full-scale span pressure step change, 10% to 90% rise time
- Note 10: Long term stability over a one year period.
- Note 11: Proof pressure is the pressure above which devices will not return to guaranteed specifications.

GENERAL DISCUSSION

The SCXL series devices give a voltage output which is directly proportional to applied pressure. The devices will give an increasing positive going output when increasing pressure is applied to pressure port B of the device. If the input pressure connections are reversed, the output will increase with decreases in pressure. The devices are ratiometric to the supply voltage and changes in the supply voltage will cause proportional changes in the offset voltage and full-scale span.

USER CALIBRATION

The SCXL devices are fully calibrated for offset and span and should therefore require little user adjustment in

most applications. For precise span and offset adjustments, refer to the applications section herein or contact the Sensym factory.

MEDIA COMPATIBILITY

SCXL devices are intended for use with non-corrosive gases. As shown in the physical construction diagram below, fluids must generally be compatible with plastic, aluminum, RTV, silicon, and glass for use with Port B. For questions concerning media compatibility, contact the factory.

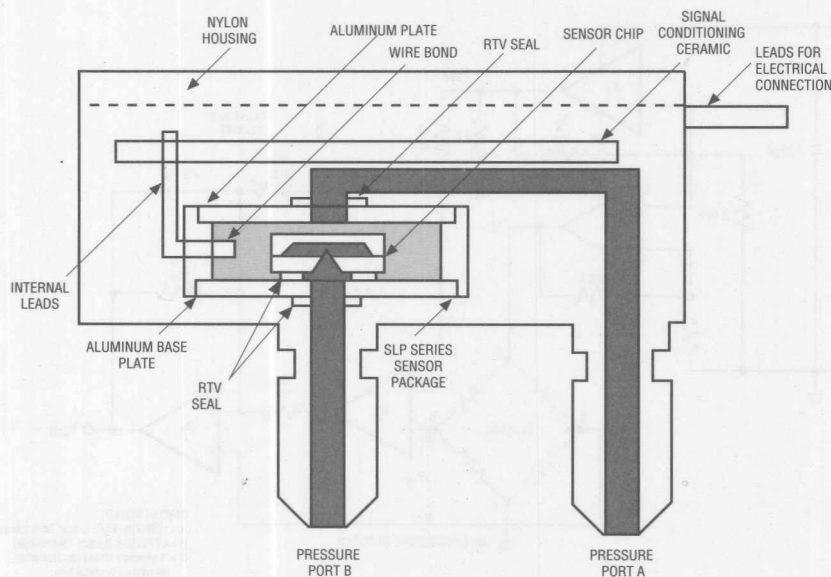
MECHANICAL AND MOUNTING CONSIDERATIONS

The SCXL nylon housing is designed for convenient pressure connection and

easy PC board mounting. To mount the device horizontally to a PC board, the leads can be bent downward and the package attached to the board using either tie wraps or mounting screws. For pressure attachment, tygon or silicone tubing is recommended.

All versions of the SCXL sensors have two (2) tubes available for pressure connection. For gage applications, pressure should be applied to port B. Port A is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port B should be used as the high pressure port and A should be used as the low pressure port.

2



Physical Construction (Cutaway Diagram — Not drawn to scale)

APPLICATION INFORMATION

Shown below is a popular circuit which gives a high level 0.5–4.5V_{DC} output for a 0–4 inch W.C. pressure input. Additional applications circuits are shown in the standard SCX series datasheet and SCX-EB evaluation board literature. For further applications information of assistance, please contact your nearest Sensym sales office or the Sensym factory.

LOW PRESSURE APPLICATION

For sensing pressure below 1 psi, the circuit shown in Figure A uses the SCXL004DN to provide a 0.5 to 4.5V output for a 0 to 4 inch of water column input pressure. This output signal is compatible with many A/D converters and hence can be used to interface to a microprocessor system. This low-cost circuit is easily adaptable to lower full-scale pressure down to 0.5 inches of water column.

CIRCUIT DESCRIPTION

The LM10 is used to provide a voltage reference for the excitation voltage (V_E), and for the voltage node V_{REF} . With this configuration, V_E and V_{REF} are not affected by noise or voltage variations in the 12V power supply. R3 is used to adjust V_{REF} to set the initial offset voltage at the output, V_{OUT} .

The pressure signal, V_{IN} , is amplified by amplifiers B1, and B2. (See Sensym Application Note SSAN-17 for details on this amplifier) R2 is used to adjust the signal gain of the circuit. The output equation is given below.

For the best circuit performance, a careful selection of components is necessary. Use wirewound pots to ensure low temperature coefficients and low long-term drift. A four-element resistor array (10 k Ω) SIP should be

used for the resistors in the amplifier stage in order to obtain closely matched values and temperature coefficients. All other resistors should be 1% metal film. Amplifiers B1, and B2 should have low offset voltages and low noise. Signal lines should be as short as possible and the power supply should be capacitively bypassed on the PC board.

ADJUSTMENT PROCEDURE

1. With zero-pressure applied, adjust the offset adjust R3, until $V_{OUT} = 0.500V$.
2. Apply full-scale pressure (4 in.WC) to port B, and adjust the full-scale adjust R2, so that $V_{OUT} = 4.500V$.
3. Repeat procedure if necessary.
 $R_1 = 169.5 \Omega$
 $= 143 \Omega + 50 \Omega \text{ pot}$

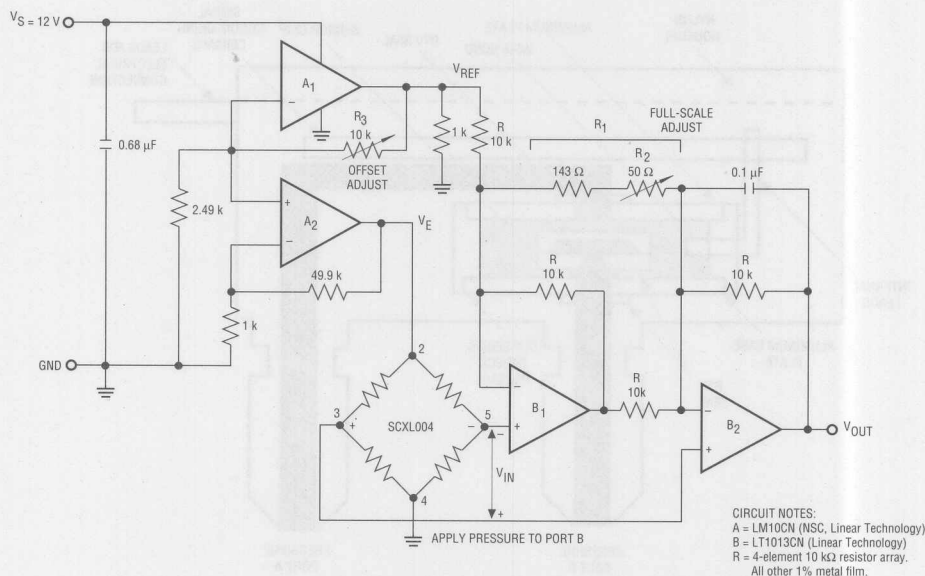
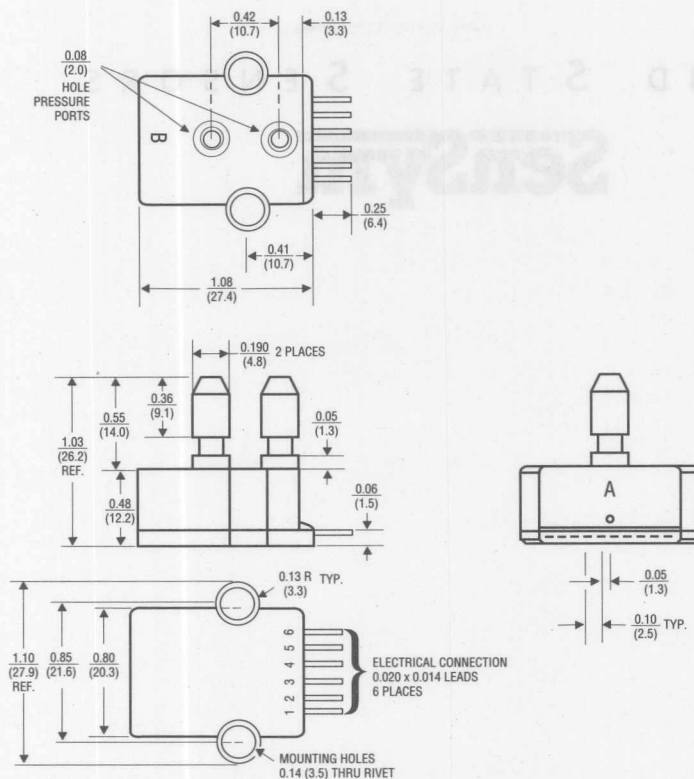


Figure A. Low Pressure Circuits Provide a 0.5 to 4.5V Output for a 0–4in. W.C. Pressure Input

PHYSICAL DIMENSIONS



DIMENSIONS IN INCHES (MILLIMETERS)
WEIGHT: 5 GRAMS
CASE MATERIAL: GLASS FILLED NYLON

WETTED MATERIAL
PORT A: GLASS FILLED NYLON, RTV, SILGEL
PORT B: GLASS FILLED NYLON, SILICON, RTV
SEE PHYSICAL CONSTRUCTION DRAWING

2

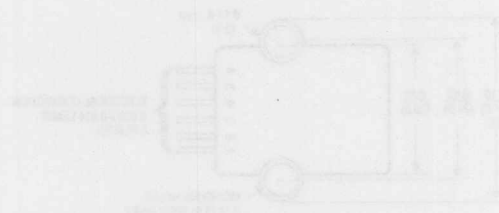
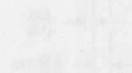
ORDERING INFORMATION

To order, use the following part number(s):

Description	Part Number
0 to 4 In. WC	SCXL004DN

SOLID STATE SENSORS

SenSym



For more information, contact your local SenSym representative or write to SenSym, Inc., 10000 N. 10th Ave., Suite 100, Denver, CO 80231.

For more information, contact your local SenSym representative or write to SenSym, Inc., 10000 N. 10th Ave., Suite 100, Denver, CO 80231.

ORDERING INFORMATION

To order, use the following part numbers:

Part Number	Description
SS-100	0 to 4 in. VAC

SOLID STATE SENSORS



SECTION 3

FULLY SIGNAL CONDITIONED SENSORS

SECTION TABLE OF CONTENTS

142SC Series

3-3

143SC Series

3-7

163SC01D48

3-9

LX16XX, LX18XX Series

3-11

SOLID STATE SENSORS

SenSym

SECTION 3 FULLY SIGNAL CONDITIONED SENSORS

SECTION 3.1 OF CONTENTS

1000 Series

1000 Series

1000 Series

1000 Series

1000

1000

1000

1000

Sensym

142SC Series 0-1psi to 0-150psi Signal Conditioned Pressure Transducers

FEATURES

- Improved Performance Replacement for Honeywell/Microswitch 140PC Series
- High Level Voltage Output
- Field Interchangeable
- Calibrated and Temperature Compensated

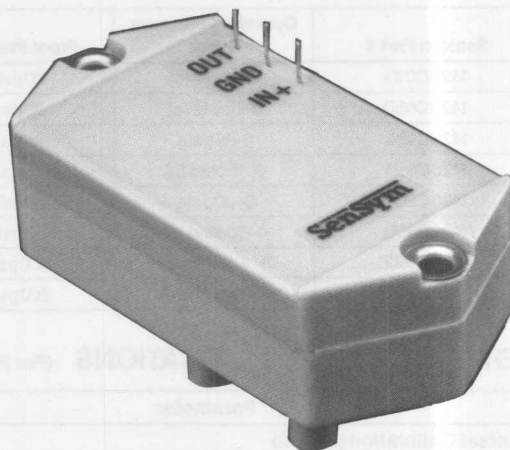
APPLICATIONS

- Medical Equipment
- Barometry
- Computer Peripherals
- HVAC

GENERAL DESCRIPTION

The 142SC series transducers provide a 1-6V output which is directly proportional to applied pressure. This series consists of eight (8) devices for monitoring differential, gage, or absolute pressures from 0-1 to 0-150 psi. These products feature a high level voltage output, complete calibration and temperature compensation.

Based on Sensym's precision SX series sensors, the 142SC series is an improved performance, direct replacement for the Honeywell/Microswitch 142PC series with equivalent pinout and package mounting dimensions.



This allows direct replacement in existing PC board layouts for the Microswitch parts. Sensym's 142SC devices offer the added advantage of tighter tolerances which give greater accuracy and field interchangeability.

These products are designed to be used with non-corrosive, non-ionic gases and liquids. For more demanding or corrosive media applications, Sensym's ST2000 stainless steel isolated family should be used.

FUNCTIONAL SPECIFICATIONS

142SC Series

Maximum Ratings

Supply Voltage	+7V _{DC} to 16V _{DC}
Output Current	
Source	10mA
Sink	5mA
Temperature Ranges	
Compensated	– 18°C to +63°C
Operating	– 40°C to +85°C
Storage	– 55°C to +125°C

Reference Conditions

Supply Voltage	8.0 ±0.01V _{DC}
Reference Temperature	25°C
Common-mode Pressure	0psig

INDIVIDUAL OPERATING CHARACTERISTICS

Sensym Part #	Operating Pressure Range	Proof Pressure	Sensitivity
142SC01D	0–1psid (g)	20psig	5V/psi
142SC05D	0–5psid (g)	20psig	1V/psi
142SC15A	0–15psia	45psia	333mV/psi
142SC15D	0–15psid (g)	45psig	333mV/psi
142SC30A	0–30psia	60psia	167mV/psi
142SC30D	0–30psid (g)	60psid	167mV/psi
142SC100D	0–100psid (g)	200psid	50mV/psi
142SC150D	0–150psid (g)	200psid	33mV/psi

PERFORMANCE SPECIFICATIONS (For All Devices) (Note 1)

Parameter	Min.	Typ.	Max.	Unit
Offset Calibration (Note 2)	0.95	1.0	1.05	V
Output at Full Pressure	5.90	6.0	6.10	V
Full-scale Span (Note 3)	4.95	5.0	5.05	V
Linearity ($P_2 > P_1$)	—	0.5	1.5	% FSO
($P_2 < P_1$) (Note 4)	—	0.2	0.75	% FSO
Temperature Shift (– 18°C to +63°C) (Note 5)	—	0.5	1.0	% FSO
Repeatability and Hysteresis	—	0.2	—	% FSO
Response Time	—	0.1	1.0	ms

Specification Notes:

- Note 1:** Performance specifications shown are at reference conditions. Specifications apply for absolute pressure devices with pressure applied to Port 1. For gage devices pressure is applied to Port 2 and Port 1 is left open to ambient. For differential pressures, Port 2 is the high pressure port. For operation at other than 8.0V_{DC} the typical ratiometricity error at 7 to 8V or 8 to 9V is ±0.50% FSO and at 9 to 12V it is ±2.00% FSO. All Sensym differential devices feature dual pressure ports and can be used as gage or differential sensors. For absolute devices, Port 2 is inactive.
- Note 2:** Offset calibration is at the lowest pressure for each given device.
- Note 3:** Full-scale span is the algebraic difference between the output voltage at full-scale pressure and the output at the lowest operating pressure.
- Note 4:** Linearity refers to the best straight line fit as measured for offset, full-scale and 1/2 full-scale pressure.
- Note 5:** Temperature shift refers to the combined effects of offset and sensitivity shifts. This is tested at – 18°C to +63°C relative to 25°C. The maximum temperature shift specification applies to all devices except the 142SC01D devices which have a maximum shift of 1.5% FSO from 5°C to 45°C.

GENERAL DISCUSSION

Sensym's 142SC series utilizes Sensym's proven SX series sensor element in combination with a custom individually laser trimmed thick film ceramic. Each device is calibrated for offset and sensitivity as well as temperature effects providing an accurate, reliable sensor for a wide variety of sensor applications.

Output Characteristics

The 142SC products give an output voltage which is directly proportional to applied pressure. For the 142SC gage and differential devices, an increasing or positive going output signal will result when increasing pressure is applied to port P2. (For absolute pressure, increases in pressure applied to port P1 produce an increasing output signal. Port P2 is inactive on absolute devices.) For standard 142SC devices the output is ratiometric to the supply voltage. Changes in the supply voltage will cause proportional changes in the offset voltage and full scale span.

User Calibration

The 142SC devices are fully calibrated for offset and span and should therefore require little or no user adjustment in most applications.

Vacuum Reference (Absolute Devices)

Absolute sensors have a hermetically sealed vacuum reference chamber within the sensor chip. The offset voltage on these units is therefore measured at vacuum, 0 psia. Since all pressure is measured relative to a vacuum reference, all changes in barometric pressure or changes in altitude will cause changes in the device output.

142SC Series

Media Compatibility

142SC devices are compatible with most clean dry gases. Because the sensor chip circuitry is coated with a protective silicon gel, many otherwise corrosive environments can be compatible with the sensors. As shown in the physical construction diagram below, fluids must generally be compatible with nylon, aluminum, RTV, and silicon, for use with Port 2. For questions concerning media compatibility, contact the factory.

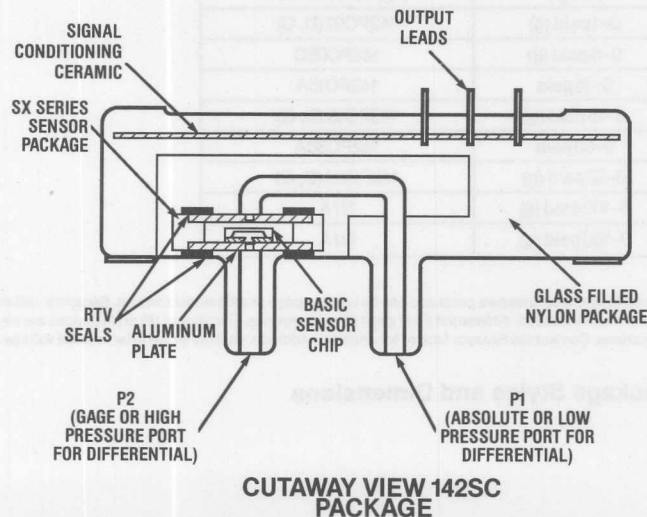
MECHANICAL AND MOUNTING CONSIDERATIONS

The 142SC package is designed for convenient pressure connection and easy PC board mounting. The package has two mounting holes allowing firm PC board connection. Mounting screws or Sensym's plastic X-mas tree clips (Part number SCXCLP) can be used for attachment. (See Application Note SSAN-25).

For pressure attachment, tygon or silicon tubing is recommended.

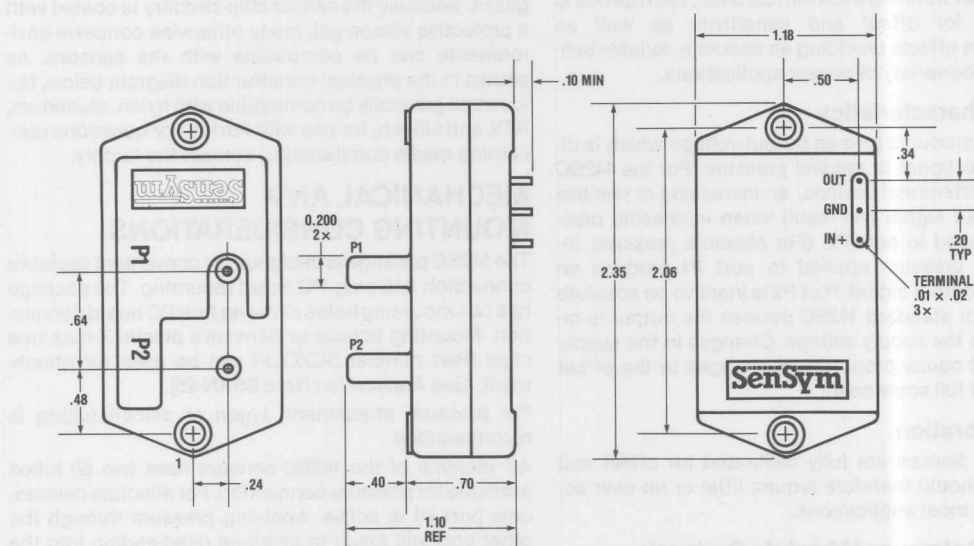
All versions of the 142SC sensors have two (2) tubes available for pressure connection. For absolute devices, only port P1 is active. Applying pressure through the other port will result in pressure dead-ending into the backside of the silicon sensor and the device will not give an output signal with pressure.

For gage applications, pressure should be applied to port P2. Port P1 is then the vent port which is left open to the atmosphere. For differential pressure applications, to get proper output signal polarity, port P2 should be used as the high pressure port and P1 should be used as the low pressure port.



MOUNTING DIMENSIONS (For Reference Only)

142SC Series



ORDERING INFORMATION

To order, use the following part numbers:

Standard Device Types

Sensym Part #	Operating Pressure Range	Honeywell/Microswitch Equivalent Part #
142SC01D	0-1psid (g)	142PC01 (D, G)
142SC05D	0-5psid (g)	142PC05D
142SC15A	0-15psia	142PC15A
142SC15D	0-15psid (g)	142PC15 (D, G)
142SC30A	0-30psia	142PC30A
142SC30D	0-30psid (g)	142PC30 (D, G)
142SC100D	0-100psid (g)	N/A
142SC150D	0-150psid (g)	N/A

Note: All Sensym differential devices feature dual pressure ports and can be used as gage or differential sensors. Sensym's differential (D) devices are therefore interchangeable with the Microswitch differential (D) or gage (G) style devices. The 141 and 143 style devices are also available for vacuum and pressure/vacuum applications. Contact the Sensym factory for details. In addition, devices which offer internal voltage regulators are also available from Sensym.

See Section 9 for Package Styles and Dimensions

Sensym

143SC Pressure Series

± 1.0 psi, ± 2.5 psi, ± 5 psi, ± 15 psi

Signal Conditioned

Pressure Transducers

FEATURES

- High-Level Voltage Output
- Field Interchangeable
- Calibrated and Temperature Compensated
- Improved Performance Replacement for Microswitch 143

APPLICATIONS

- Medical Equipment
- Industrial Controls
- Precision Lab Equipment

GENERAL DESCRIPTION

The 143SC series transducers provide a 1-6V output which is directly proportional to applied pressure. This series consists of three (3) devices for measuring differential or gage pressures from ± 2.5 psi to ± 15 psi.

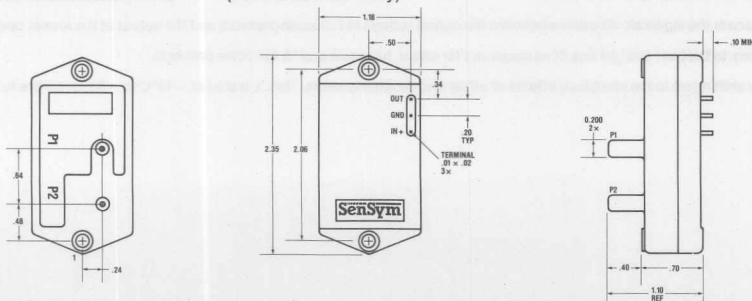
Based on Sensym's precision SX series sensors, the 143 series is an improved performance, direct replacement for the Honeywell/Microswitch 143PC series with equivalent pin-out and package mounting dimensions. This

allows direct replacement in existing PC board layouts for the Microswitch parts.

The transducers are packaged in a thermoplastic nylon housing, providing convenient pressure and P.C. board mounting. They are designed for use with non-corrosive gases and liquids. For corrosive media applications, Sensym's stainless steel isolated transducers should be used.

MOUNTING DIMENSIONS

(For Reference Only)



GENERAL SPECIFICATIONS

143SC

Maximum Ratings

Supply Voltage	+7 V _{DC} to 16 V _{DC}
Output Current	
Source	10 mA
Sink	5 mA
Temperature Ranges	
Compensated	– 18°C to +63°C
Operating	– 40°C to +85°C
Storage	– 55°C to +125°C

Reference Conditions

Supply Voltage	8.0 ± 0.01 V _{DC}
Reference Temperature	25°C
Common-mode Pressure	0 psig

PERFORMANCE SPECIFICATIONS⁽¹⁾

Parameter	Min.	Typ.	Max.	Unit
Offset Calibration ⁽²⁾	3.45	3.50	3.55	V
Output at Full Pressure	5.90	6.0	6.10	V
Full-scale Span ⁽³⁾	—	5.0	—	V
Linearity (P2 > P1) ⁽⁴⁾	—	0.5	1.5	%FSO
(P2 < P1)	—	0.2	0.75	%FSO
Temperature Shift (– 18°C to +63°C) ⁽⁵⁾	—	0.5	1.0	%FSO
Repeatability and Hysteresis	—	0.2	—	%FSO
Response Time	—	0.1	1.0	ms

INDIVIDUAL OPERATING CHARACTERISTICS

SenSym Part #	Operating Pressure Range	Proof Pressure	Sensitivity
143SC01D	–1.0 to +1.0 psid (g)	20 psig	2.5V/psi
143SC03D	–2.54 to +2.5 psid (g)	20 psig	1.0V/psi
143SC05D	–5 to +5 psid (g)	30 psig	0.50V/psi
143SC15D	–15 to +15 psid (g)	50 psig	0.177V/psi

See Section 9 for Package Styles and Dimensions

Specification Notes:

- Note 1:** Performance specifications shown are at reference conditions, pressure applied to port P2. For operation at other than 8.0 V_{DC} the typical radiometricity error at 7 or 8 V to 9 V is ± 0.50% FSO and at 9 to 12 V it is ± 2.00% FSO.
- Note 2:** Offset calibration is at 0 psig for each device.
- Note 3:** Full-scale span is the algebraic difference between the output voltage at full-scale pressure and the output at the lowest operating pressure.
- Note 4:** Linearity refers to the best straight line fit as measured for offset, full-scale and 1/2 full-scale pressure.
- Note 5:** Temperature shift refers to the combined effects of offset and sensitivity shifts. This is tested at – 18°C to +63°C relative to 25°C.

Sensym

163SC01D48 Transducer – 20 to +120 cm H₂O

FEATURES

- Superior Price/Performance Replacement for Honeywell/Microswitch 163PC01D48
- Low Pressure Measurements
- High-Level Voltage Output
- Field Interchangeable
- Calibrated and Temperature Compensated

APPLICATIONS

- Medical Equipment
- HVAC
- Flow Monitoring

GENERAL DESCRIPTION

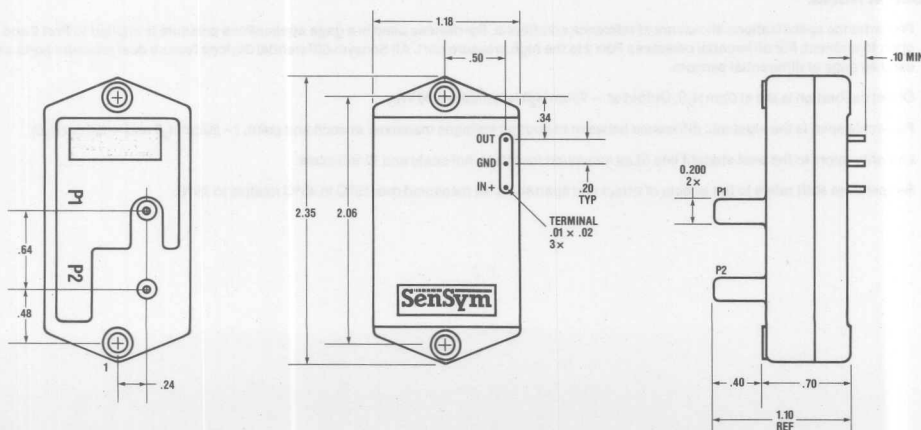
The 163SC01D48 transducer provides a signal conditioned output which is directly proportional to applied pressure. This transducer is intended for monitoring low pressures of – 20 to +120 cm of water, and feature a high-level voltage output which is calibrated and temperature compensated.

Based on Sensym's precision SX series sensors, the 163SC01D48 is a superior price/performance replacement for the Honeywell/Microswitch 163PC01D48. Offering equivalent pinout and package mounting dimensions, the 163SC01D48 allows direct replacement in existing PC board layouts for the Microswitch in existing PC board layouts for the Microswitch devices.

These devices are designed to be used with non-corrosive, non-ionic gases and liquids. For more demanding or corrosive media applications, Sensym's ST2000 stainless steel isolated family should be used.

3

PHYSICAL DIMENSIONS



Maximum Ratings

Supply Voltage	6V _{DC} to 12V _{DC}
Output Current	
Source	10 mA
Sink	5 mA
Temperature Ranges	
Compensated	+15°C to +45°C
Operating	– 40°C to +85°C
Storage	– 55°C to +125°C
Overpressure	350 cm H ₂ O

Reference Conditions

Supply Voltage	10.0 ± 0.01V _{DC}
Reference Temperature	25°C
Common-mode Pressure	0 cm H ₂ O

PERFORMANCE SPECIFICATIONS (Note 1)

Parameter	Min.	Typ.	Max.	Unit
Pressure Range	– 20	—	+120	cm H ₂ O
Zero Pressure Offset (Note 2)	1.564	1.714	1.864	V
Full-scale Output	5.850	6.000	6.150	V
Full-scale Span (Note 3)	—	5.000	—	V
Sensitivity	—	35.70	—	mV/cm H ₂ O
Linearity (Note 4)	—	±0.50	—	% FSO
Temperature Effect on Offset (Note 5)	—	±0.50	±0.75	% FSO
Temperature Effect on Span (Note 5)	—	±0.75	±1.00	% FSO
Repeatability and Hysteresis	—	±0.15	—	% FSO
Response Time	—	0.10	1.00	ms

ORDERING INFORMATION

To order, use the following part numbers:

Standard Device Types

Sensym Part #	Operating Pressure Range	Honeywell/Microswitch Equivalent Part #
163SC01D48	– 20 to +120 cm H ₂ O	163PC01D48

See Section 9 for Package Styles and Dimensions

Specification Notes:

- Note 1:** Performance specifications shown are at reference conditions. For devices used in a gage applications pressure is applied to Port 2 and Port 1 is left open to ambient. For differential pressures Port 2 is the high pressure port. All Sensym differential devices feature dual pressure ports and can be used as gage or differential sensors.
- Note 2:** Offset calibration is set at 0 cm H₂O. Output at – 20 cm H₂O is typically 1.00V_{DC}.
- Note 3:** Full-scale span is the algebraic difference between the output voltages measured at each end point. (– 20 cm H₂O and +120 cm H₂O)
- Note 4:** Linearity refers to the best straight line fit as measured for offset, full-scale and 1/2 full-scale.
- Note 5:** Temperature shift refers to the effects of offset and span shifts as measured over 15°C to 45°C relative to 25°C.

Sensym

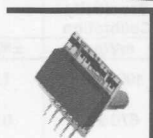
LX16XX and LX18XX Series Low and Mid-Pressure Range Signal Conditioned Pressure Transducers — 10Volt Output

General Description

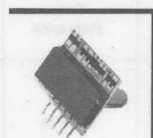
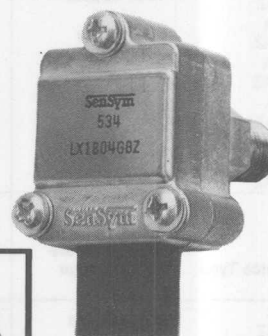
These are fully signal-conditioned pressure transducers with temperature compensation and high-level output voltage. The LX16XX series transducers are provided in compact ceramic packages for easy PC board mounting. The LX18XX series transducers are provided in die cast zinc housings with 1/8" NPT fittings, and a 3-pin Molex connector for easy, low cost electrical interface.

Features

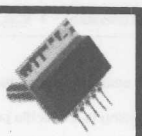
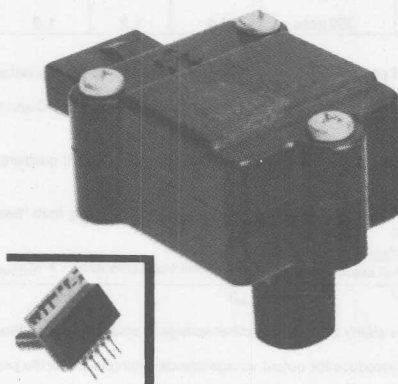
- ± 5 psi to 0–300psi
- High level output voltage, 2.5V to 12.5V
- Temperature compensated
- PC board mountable versions, LX16XX series
- Rugged zinc housings, LX18XX
- Backward gage version for aqueous working fluids
- Silguard option on low-pressure and all GB devices
- Field interchangeability
- Available from local stocking distributors



DIFFERENTIAL PRESSURE TRANSDUCERS:
LO Port Compatible with Aqueous Working Fluids. Ceramic or High Common-Mode Zinc Housing.



BACKWARD GAGE PRESSURE TRANSDUCERS:
Working Fluid Port Compatible with Aqueous Fluids. Ceramic, Zinc Housings.



ABSOLUTE PRESSURE TRANSDUCER:
Enclosed Vacuum Reference
Ceramic, Zinc Housings.

Absolute Pressure Transducer Characteristics

Maximum Ratings

Excitation Voltage (Note 1)	30V
Output Current	
Source	20mA
Sink	10mA
Transducer Bias Current	20mA
Operating Temperature Range (Note 2)	-40°C to +105°C
Lead Temperature (Soldering, 10 seconds)	200°C

Reference Conditions (Note 3)

Excitation Voltage, V_E (Note 1)	15V
Reference Temperature	25°C
Reference Temperature Range	0 to 80°C
Reference Offset Pressure	(Note 4)

Typical Characteristics

Output Voltage Change to Excitation Voltage Change	0.5%
Output Impedance	< 50Ω
Electrical Noise Equivalent ($0 < f \leq 1$ kHz)	0.04% Span
Natural Frequency of Sensor Diaphragm	> 50kHz
Transducer Bias Current	11 – 15mA
Full-Scale Pressure Cycles (Note 9)	tbd
Leak Area (Air Media)	< 10^{-7} cm ²

Performance Characteristics

Device Type	Operating Pressure Range	Maximum Over Pressure	Guaranteed Specifications				Typ. Specifications		
			Offset Calibration V (Note 4)	Offset Shift w/ Temperature 0°C to 80°C (Note 5)	Linearity Hysteresis Repeatability (Note 6)		Span Shift w/ Temperature 0°C to 80°C (Note 5)		
					±%FS	%FS ±psi			
LX1601A LX1801AZ	10 to 20 psia	45 psia	2.5 ± 0.70	3.3	0.67	0.067	2.75		
LX1602A LX1802AZ	0 to 15 psia	45 psia	2.5 ± 0.50	2.75	0.67	0.10	2.75		
LX1603A LX1803AZ	0 to 30 psia	45 psia	2.5 ± 0.35	1.65	0.67	0.20	1.65		
LX1610A LX1810AZ	0 to 60 psia	100 psia	2.5 ± 0.30	1.65	0.67	0.40	1.65		
LX1620A LX1820AZ	0 to 100 psia	150 psia	2.5 ± 0.30	1.10	0.67	0.67	1.10		
LX1830AZ	0 to 300 psia	350 psia	2.5 ± 0.30	1.10	0.67	2.0	1.10		
Device Type	Operating Pressure Range	Maximum Over Pressure	Typical Specifications						
			Offset Characteristics				Span Characteristics		
			Repeatability (Note 7)		Stability (Note 8)		Sensitivity Calibration	Stability (Note 8)	
			±%FS	±psi	±%FS	±psi	mV/psi	±%FS	±psi
LX1601A LX1801AZ	10 to 20 psia	45 psia	0.5	0.05	5.0	0.5	1000 ± 20	1.0	0.1
LX1602A LX1802AZ	0 to 15 psia	45 psia	0.4	0.06	3.3	0.5	670 ± 13	0.7	0.1
LX1603A LX1803AZ	0 to 30 psia	45 psia	0.4	0.12	1.7	0.5	333 ± 6.7	0.3	0.1
LX1610A LX1810AZ	0 to 60 psia	100 psia	0.4	0.24	1.5	0.9	167 ± 3.3	0.3	0.2
LX1620A LX1820AZ	0 to 100 psia	150 psia	0.4	0.40	1.2	1.2	100 ± 2	0.3	0.3
LX1830AZ	0 to 300 psia	350 psia	0.4	1.2	1.0	3.0	33.3 ± 0.67	0.3	0.9

Specification Notes:

Note 1: The LX16XX and LX18XX series are not polarity protected. Incorrect application of excitation voltage or ground to the wrong pin can cause electrical failure.

Note 2: Device performance characteristics apply 0 to +80°C, device is functional from -40°C to 0°C and 80°C to +105°C and all the temperature dependent errors are typically doubled over the additional temperature range.

Note 3: Conditions at which device performance characteristics apply.

Note 4: Offset Reference Pressure—for gage and differential devices offset pressure is ambient pressure, for absolute devices offset pressure is the lowest pressure in the pressure range.

Note 5: Temperature tested at 80°C relative to 25°C.

Note 6: Linearity—the maximum deviation of measured output, at constant temperature (25°C), from "best straight line" through three points (offset pressure, full scale pressure, one-half full scale pressure).

$$\% \text{ FS error} = \frac{V_{1/2 \text{ full scale}} - \left\{ \left(\frac{V_{\text{full scale}} - V_{\text{offset}}}{\text{full scale pressure}} \right) \times \left(\frac{1}{2} \text{ full scale pressure} \right) + V_{\text{offset}} \right\}}{2(V_{\text{full scale}})} \times 100\%$$

(V = measured value for each device)

Note 7: Offset Repeatability—the transducer's ability to reproduce offset voltage at constant temperature (25°C) when cycled through its full operating pressure range.

Note 8: Stability—the transducer's ability to reproduce the output voltage corresponding to a specific pressure and temperature in a period of one year during which maximum ratings are not exceeded.

Note 9: Pressure cycle fatigue is a package related parameter. For LX18XX devices the maximum cycle life is limited by pressure magnitude and package O-ring. LX16XX devices are not limited by O-ring.

Differential Pressure Transducer Characteristics

Maximum Ratings

Excitation Voltage (Note 1)	30 V
Output Current	
Source	20 mA
Sink	10 mA
Transducer Bias Current	20 mA
Operating Temperature Range (Note 2)	-40°C to +105°C
Lead Temperature (Soldering, 10 seconds)	200°C
Pressure at Any Port	
LX16XXD	350 psig
LX18XXDZ	

Reference Conditions (Note 3)

Excitation Voltage, V_E (Note 1)	15 V
Reference Temperature	25°C
Reference Temperature Range	0 to 80°C

Reference Offset Pressure	(Note 4)
Common-Mode Line Pressure	
LX16XXD	
LX18XXDZ	0 psig

Typical Characteristics

Output Voltage Change to Excitation	0.5%
Voltage Change	< 50Ω
Output Impedance	> 50 kHz
Electrical Noise Equivalent ($0 \leq f \leq 1$ kHz)	0.04% Span
Natural Frequency of Sensor Diaphragm	tbd
Transducer Bias Current	11 – 15 mA
Full-Scale Pressure Cycles (Note 9)	tbd
Offset Shift vs. Common-Mode Pressure	< 10^{-7} cm ²
Leak Area (Air Media)	

Performance Characteristics

Device Type	Operating Pressure Range	Maximum Over Pressure	Guaranteed Specifications				Typ. Specifications	
			Offset Calibration V (Note 4)	Offset Shift w/ Temperature 0°C to 80°C (Note 5)	Linearity Hysteresis Repeatability (Note 6)		Span Shift w/ Temperature 0°C to 80°C (Note 5)	
					±%FS	%FS	±psi	±%FS
LX1601D	0 to ±5 psid	45 psid	7.5 ± 0.70	3.3	0.67	0.067	2.75	
LX1801DZ	0 to 15 psid	45 psid	2.5 ± 0.50	2.75	0.67	0.10	2.75	
LX1602D	0 to 30 psid	45 psid	2.5 ± 0.35	1.65	0.67	0.20	1.65	
LX1802DZ	0 to ±15 psid	45 psid	7.5 ± 0.35	1.65	0.67	0.20	1.65	
LX1603D	0 to 60 psid	100 psid	2.5 ± 0.30	1.65	0.67	0.40	1.65	
LX1803DZ	0 to 100 psid	150 psid	2.5 ± 0.30	1.10	0.67	0.67	1.10	
LX1604D	0 to 300 psid	350 psid	2.5 ± 0.30	1.10	0.67	2.0	1.10	
LX1804DZ								
LX1610D								
LX1810DZ								
LX1620D								
LX1820DZ								
LX1830DZ								

Device Type	Operating Pressure Range	Maximum Over Pressure	Typical Specifications					
			Offset Characteristics				Span Characteristics	
			Repeatability (Note 7)		Stability (Note 8)		Sensitivity Calibration	Stability (Note 8)
			±%FS	±psi	±%FS	±psi	mV/psi	±%FS
LX1601D	0 to ±5 psid	45 psid	0.5	0.05	5.0	0.5	1000 ± 20	1.0
LX1801DZ	0 to 15 psid	45 psid	0.4	0.06	3.3	0.5	670 ± 13	0.7
LX1602D	0 to 30 psid	45 psid	0.4	0.12	1.7	0.5	333 ± 6.7	0.3
LX1802DZ	0 to ±15 psid	45 psid	0.4	0.12	1.7	0.5	333 ± 6.7	0.3
LX1603D	0 to 60 psid	100 psid	0.4	0.24	1.5	0.9	167 ± 3.3	0.3
LX1803DZ	0 to 100 psid	150 psid	0.4	0.40	1.2	1.2	100 ± 2	0.3
LX1604D	0 to 300 psid	350 psid	0.4	1.2	1.0	3.0	33.3 ± 0.67	0.3
LX1804DZ								
LX1610D								
LX1810DZ								
LX1620D								
LX1820DZ								
LX1830DZ								

Specification Notes:

Note 1: The LX16XX and LX18XX series are not polarity protected. Incorrect application of excitation voltage or ground to the wrong pin can cause electrical failure.

Note 2: Device performance characteristics apply 0 to +80°C, device is functional from -40°C to 0°C and 80°C to +105°C and all the temperature dependent errors are typically doubled over the additional temperature range.

Note 3: Conditions at which device performance characteristics apply.

Note 4: Offset Reference Pressure—for gage and differential devices offset pressure is ambient pressure, for absolute devices offset pressure is the lowest pressure in the pressure range.

Note 5: Temperature tested at 80°C relative to 25°C.

Note 6: Linearity—the maximum deviation of measured output, at constant temperature (25°C), from "best straight line" through three points (offset pressure, full scale pressure, one-half full scale pressure).

$$\% \text{ FS error} = \frac{V_{1/2 \text{ full scale}} - \left\{ \left(\frac{V_{\text{full scale}} - V_{\text{offset}}}{\text{full scale pressure}} \right) \times \left(\frac{1}{2} \text{ full scale pressure} \right) + V_{\text{offset}} \right\}}{2(V_{\text{full scale}})} \times 100\%$$

(V = measured value for each device)

Note 7: Offset Repeatability—the transducer's ability to reproduce offset voltage at constant temperature (25°C) when cycled through its full operating pressure range.

Note 8: Stability—the transducer's ability to reproduce the output voltage corresponding to a specific pressure and temperature in a period of one year during which maximum ratings are not exceeded.

Note 9: Pressure cycle fatigue is a package related parameter. For LX18XX devices the maximum cycle life is limited by pressure magnitude and package O-ring. LX16XX devices are not limited by O-ring.

Backward Gage Pressure Transducer Characteristics

Maximum Ratings

Excitation Voltage (Note 1)	30V
Output Current	
Source	20mA
Sink	10mA
Transducer Bias Current	20mA
Operating Temperature Range (Note 2)	-40°C to +105°C
Lead Temperature (Soldering, 10 seconds)	200°C

Reference Conditions (Note 3)

Excitation Voltage, V_E (Note 1)	15V
Reference Temperature	25°C
Reference Temperature Range	0 to 80°C
Reference Offset Pressure	(Note 4)

Typical Characteristics

Output Voltage Change to Excitation	
Voltage Change	0.5%
Output Impedance	< 50 Ω
Electrical Noise Equivalent ($0 \leq f \leq 1$ kHz)	0.04% Span
Natural Frequency of Sensor Diaphragm	> 50 kHz
Transducer Bias Current	11 - 15 mA
Full-Scale Pressure Cycles (Note 9)	tbd
Leak Area (Air Media)	< 10^{-7} cm ²

Performance Characteristics

Device Type	Operating Pressure Range	Maximum Over Pressure	Guaranteed Specifications				Typ. Specifications	
			Offset Calibration V (Note 4)	Offset Shift w/ Temperature 0°C to 80°C (Note 5)	Linearity Hysteresis Repeatability (Note 6)		Span Shift w/ Temperature 0°C to 80°C (Note 5)	
					$\pm\%$ FS	$\pm$ psi	$\pm\%$ FS	
LX1601GB	0 to ± 5 psig	45 psig	7.5 $\pm$ 0.70	3.3	0.67	0.067	2.75	
LX1801GBZ								
LX1602GB	0 to 15 psig	45 psig	2.5 $\pm$ 0.50	2.75	0.67	0.10	2.75	
LX1802GBZ								
LX1603GB	0 to 30 psig	45 psig	2.5 $\pm$ 0.35	1.65	0.67	0.20	1.65	
LX1803GBZ								
LX1604GB	0 to ± 15 psig	45 psig	7.5 $\pm$ 0.35	1.65	0.67	0.20	1.65	
LX1804GBZ								
LX1610GB	0 to 60 psig	100 psig	2.5 $\pm$ 0.30	1.65	0.67	0.40	1.65	
LX1810GBZ								
LX1620GB	0 to 100 psig	150 psig	2.5 $\pm$ 0.30	1.10	0.67	0.67	1.10	
LX1820GBZ								
LX1830GBZ	0 to 300 psig	350 psig	2.5 $\pm$ 0.30	1.10	0.67	2.0	1.10	

Device Type	Operating Pressure Range	Maximum Over Pressure	Typical Specifications						
			Offset Characteristics				Span Characteristics		
			Repeatability (Note 7)		Stability (Note 8)		Sensitivity Calibration	Stability (Note 8)	
			$\pm\%$ FS	$\pm$ psi	$\pm\%$ FS	$\pm$ psi	mV/psi	$\pm\%$ FS	$\pm$ psi
LX1601GB	0 to ± 5 psig	45 psig	0.5	0.05	5.0	0.5	1000 $\pm$ 20	1.0	0.1
LX1801GBZ									
LX1602GB	0 to 15 psig	45 psig	0.4	0.06	3.3	0.5	670 $\pm$ 13	0.7	0.1
LX1802GBZ									
LX1603GB	0 to 30 psig	45 psig	0.4	0.12	1.7	0.5	333 $\pm$ 6.7	0.3	0.1
LX1803GBZ									
LX1604GB	0 to ± 15 psig	45 psig	0.4	0.12	1.7	0.5	333 $\pm$ 6.7	0.3	0.1
LX1804GBZ									
LX1610GB	0 to 60 psig	100 psig	0.4	0.24	1.5	0.9	167 $\pm$ 3.3	0.3	0.2
LX1810GBZ									
LX1620GB	0 to 100 psig	150 psig	0.4	0.40	1.2	1.2	100 $\pm$ 2	0.3	0.3
LX1820GBZ									
LX1830GBZ	0 to 300 psig	350 psig	0.4	1.2	1.0	3.0	33.3 $\pm$ 0.67	0.3	0.9

Specification Notes:

Note 1: The LX16XX and LX18XX series are not polarity protected. Incorrect application of excitation voltage or ground to the wrong pin can cause electrical failure.

Note 2: Device performance characteristics apply 0 to +80°C, device is functional from -40°C to 0°C and 80°C to +105°C and all the temperature dependent errors are typically doubled over the additional temperature range.

Note 3: Conditions at which device performance characteristics apply.

Note 4: Offset Reference Pressure—for gage and differential devices offset pressure is ambient pressure, for absolute devices offset pressure is the lowest pressure in the pressure range.

Note 5: Temperature tested at 80°C relative to 25°C.

Note 6: Linearity—the maximum deviation of measured output, at constant temperature (25°C), from "best straight line" through three points (offset pressure, full scale pressure, one-half full scale pressure).

$$\% \text{ FS error} = \frac{V_{1/2 \text{ full scale}} - \left\{ \left(\frac{V_{\text{full scale}} - V_{\text{offset}}}{\text{full scale pressure}} \right) \times \left(\frac{1}{2} \text{ full scale pressure} \right) + V_{\text{offset}} \right\}}{2(V_{\text{full scale}})} \times 100\%$$

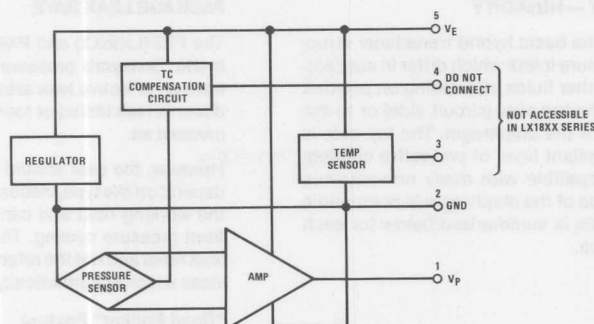
(V = measured value for each device)

Note 7: Offset Repeatability—the transducer's ability to reproduce offset voltage at constant temperature (25°C) when cycled through its full operating pressure range.

Note 8: Stability—the transducer's ability to reproduce the output voltage corresponding to a specific pressure and temperature in a period of one year during which maximum ratings are not exceeded.

Note 9: Pressure cycle fatigue is a package related parameter. For LX18XX devices the maximum cycle life is limited by pressure magnitude and package O-ring. LX16XX devices are not limited by O-ring.

Schematic Diagram



Application Guide

ACCURACY SPECIFICATIONS — AUTO-REFERENCING

Error parameters are specified separately for offset and span. These errors are independent which allows easy computation of error bands, recalibration, and use of auto-referencing, a technique of automatic recalibration. For a detailed discussion of accuracy specifications and auto-referencing, see application notes.

Consulting the Handbook

It is recommended that the application notes be consulted before using any Sensym pressure transducer. These sections contain comprehensive information on auto-referencing, pressure transducer installation and many applications. The following supplements those sections for the LX16XX and LX18XX families of pressure transducers.

Signal Conditioning — Hybrid vs. Monolithic

The LX16XX and LX18XX series transducers are fully signal-conditioned pressure transducers with temperature compensation, single-ended 10V output span, and internal voltage regulation to allow operation with a 15V to 30V supply. They offer easy electrical interface and high accuracy over a wide temperature range. If the user has the capability of developing temperature compensation circuits (or if the temperature compensation is not

required), the LX05XX or LX06XX series monolithic sensors may offer a viable, low-cost alternative (see Section 2).

LX16XX vs LX18XX

As shown in *Figure 2*, the LX16XX series transducers are provided in a ceramic SIP (single-in-line package) for each PC board mounting, with pressure ports suitable for attachment of flexible tubing. The sensor chip is attached with a stress-relieving mount to minimize stress transfer; but to achieve high accuracy, the user must avoid stressing the ceramic package in installation (Section 7). The advantages of using the LX16XX series are low-cost and high-density packaging. They are available with operating pressure ranges up to 100psi.

The LX18XX series devices are LX16XX devices enclosed in rugged zinc housings, with internal, Buna-N O-ring seals, and 1/8" NPT fittings. They mate with standard connectors and offer protection against rough handling and stress from the pressure system. The stress protection feature is enhanced in the LX18XXDZ high common-mode differential versions which can measure small pressure differentials on a line pressurized up to 350psig. The LX18XX is available with operating pressure ranges up to 300psi.

Application Guide (Continued)

MEDIA COMPATIBILITY—HUMIDITY

As shown in *Figure 1*, the basic hybrid transducer structure allows for two pressure inlets which differ in susceptibility to moisture and other fluids, depending on whether the fluid is applied to the top side (circuit side) or to the back side (cavity side) of the diaphragm. The top side is coated with a thin compliant layer of protective coating. The circuit side is compatible with many non-aqueous fluids while the back side of the diaphragm is compatible with aqueous fluids. This is summarized below for each pressure transducer type.

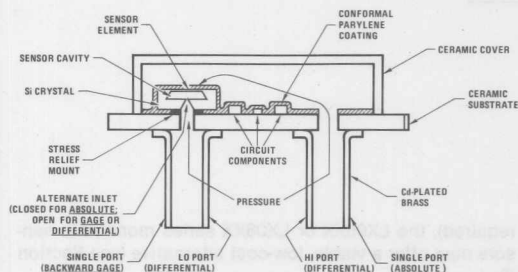


FIGURE 1. Basic LX16XX Series IC Pressure Transducer Structure

The circuit-side inlet is the working fluid port for absolute transducers and the HI port for differential transducers. It is the reference port for backward gage transducers. It can be used with most fuels, oils, refrigerants, hydraulic fluids, and non-corrosive gases (for refrigerants, see LX18XXGBR Data Sheet). But moisture condensate or other ionic, acidic or corrosive fluids can cause erroneous readings and electrical failure.

The cavity-side inlet is the working fluid port for backward gage transducers and the LO port for differential transducers. It can be used with aqueous fluids but cannot be used with acids and other fluids corrosive to device construction material (brass, zinc, nylon, solder, alumina, silicon and Buna-N).

Hence, the *backward gage* version can be used with many aqueous working fluids but requires a dry ambient. The *differential* version can tolerate aqueous fluids in the LO port but not in the HI port. The *absolute* version requires dry working fluids, but the ambient can be humid.

PACKAGE LEAK RATE

The PX6 (LX16XX) and PX8 (LX18XX) packages are not hermetic. Sensym's pressure transducers are guaranteed to have an effective leak area less than 10^{-7} cm^2 . Each transducer is leak tested at room temperature with 45 psig compressed air.

However, the user should be aware that the leak rate can depend on the type, viscosity, pressure, and temperature of the working fluid and can increase with fatigue resulting from pressure cycling. This leak rate applies to package leak rates and not the reference chamber in absolute (A) devices which is hermetically sealed.

"Dead-Ending" Feature

If the pressure applied to the LX16XXA or LX18XXA (N, Z) exceeds proof pressure (maximum specified operating pressure), the silicon diaphragm could rupture. But, unlike gage transducers, the absolute devices are "dead-ended" so that diaphragm rupture does not necessarily result in fluid leakage.

INPUT/OUTPUT POLARITY

The output signal is at pin 1 for all LX16XX series signal-conditioned transducers. *Figure 2* shows the pinout for these transducers, with pressure ports extending out of the drawing.

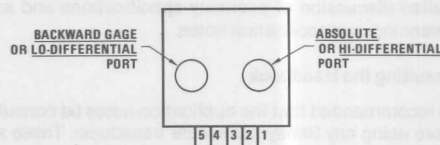


FIGURE 2. LX16XX Pinout, Portside View

The output signal of absolute transducers is positive-going for increasing pressure applied to the absolute port.

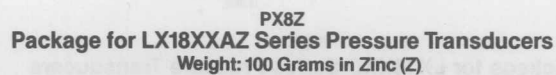
The output signal of backward gage transducers is positive-going for increasing pressure applied to the backward gage port.

The output signal of differential transducers is positive going for increasing pressure applied to the HI port relative to the LO port.

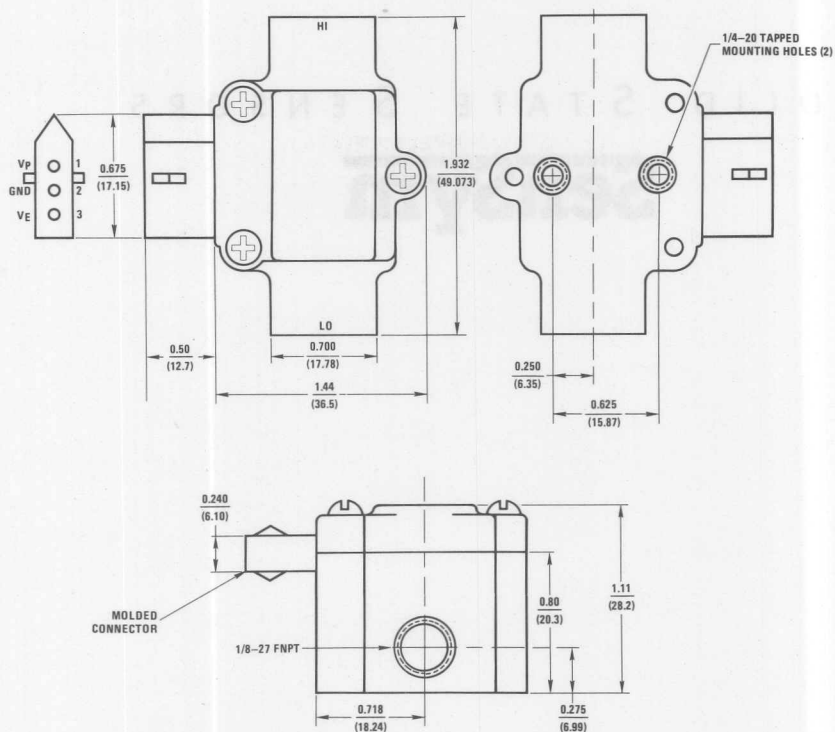
WARNING

The LX16XX and LX18XX series are not polarity protected. Incorrect application of excitation voltage or ground to the wrong pin can cause electrical failure.

3



Typical Physical Dimensions (Continued) inches (millimeters)



PX8DZ

Package for LX18XXDZ Series Zinc Cast Pressure Transducers
Weight: 170 Grams

LX18XX (PX8) Mating Connector

Vendor	Connector No.	Male Pin No.
Litton-Winchester Win-Com Series	59-03P1000	159-1018P
Waldon/Molex	03-09-2031	02-09-2103
Molex—without mounting ears	03-09-2032	

SOLID STATE SENSORS

SenSym

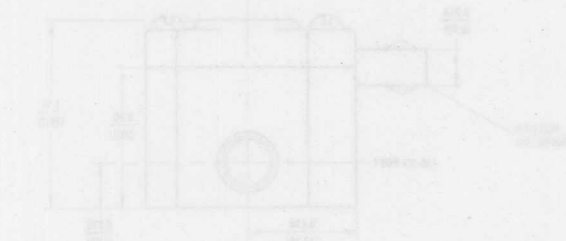


FIGURE 1
Package for LK1000 Series Low Cost Pressure Transducers
Mounting Tab

LK1000 Series Mounting Dimensions

Feature	Dimension (in)	Dimension (mm)
Mounting Tab	0.050 ± 0.005	1.27 ± 0.13
Mounting Hole	0.125 ± 0.005	3.18 ± 0.13
Package Width	0.250 ± 0.005	6.35 ± 0.13

SOLID STATE SENSORS

SenSym

SECTION 4 STAINLESS STEEL ISOLATED SENSORS

SECTION TABLE OF CONTENTS

SSX Series

4-3

ST2-G Series

4-5

ST2-G4A Series

4-12

SOLID STATE SENSORS

SenSym

**Low Cost, Precision,
Stainless Steel Sensor**
0–15 psig, 0–30 psig, 0–100 psig,
0–150 psig, 0–300 psig, 0–500 psig
Corrosive Liquids or Gases

**SSX15G, SSX30G, SSX100G,
SSX150G, SSX300G, SSX500G
PRESSURE SENSORS**

Features

- Low Cost
- Rugged — Stainless Steel
- 0.30% Accuracy
- Wide Temperature Operation
- Factory Calibrated and Temperature Compensated to Within $\pm 1\%$
- Reliable Semiconductor Technology

Applications

- Energy Management
- Process Control
- Robotics
- Sewage and Water Treatment
- Hydraulics
- Off-Road Vehicles
- Agricultural Vehicles

Description

The stainless steel SSX "G" Series devices were developed for pressure applications that involve measurement of a hostile media in harsh environments. These rugged devices are factory calibrated and temperature compensated for operation from 0 to $+70^{\circ}\text{C}$ and with slightly reduced performance, will operate over the range from -40°C to $+125^{\circ}\text{C}$. This precise laser trimmed factory calibration and temperature compensation allows for field interchangeability without recalibration for most applications.

The SSX "G" devices each provide a closely trimmed full scale output when operated from a 12V supply. However, the output of the bridge is ratiometric and operation from any DC supply from +5V to +30V is acceptable.

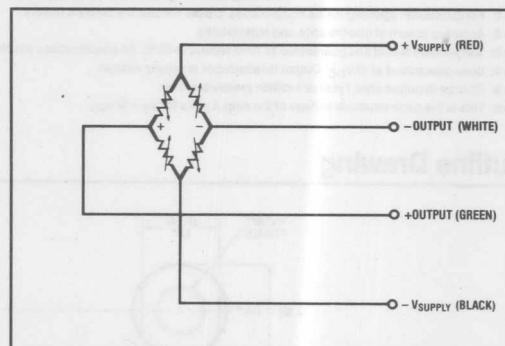
These devices use the latest in silicon technology to provide accurate, reliable and repeatable pressure sensing that is stable with time and temperature. The stainless steel case and connector cable give these parts excellent resistance to EMI and RFI. The devices feature a $\frac{1}{8}$ " female NPT fitting to allow easy connection to a variety of standard male pressure connection fittings.

The SSX "G" Series devices are rugged and reliable transducers for use in a wide variety of pressure sensing applications where corrosive liquids or gases are monitored. Contact your local Sensym representative or the Sensym factory for further details.



4

Electrical Connection



Ordering Information

To order, use the following part numbers:

Part Number	Operating Pressure Range
SSX15G	0–15 psig
SSX30G	0–30 psig
SSX100G	0–100 psig
SSX150G	0–150 psig
SSX300G	0–300 psig
SSX500G	0–500 psig

SSX15G, SSX30G, SSX100G, SSX300G

Functional Specifications: Service: Liquid, gas or vapor compatible with 303 stainless steel.¹

Part Number	Operating Pressure Range	Maximum Over Pressure	Full-Scale Output (Nominal)
SSX15G	0–15 psig	30 psig	90 mV
SSX30G	0–30 psig	60 psig	90 mV
SSX100G	0–100 psig	200 psig	100 mV
SSX150G	0–150 psig	300 psig	90 mV
SSX300G	0–300 psig	450 psig	60 mV
SSX500G	0–500 psig	600 psig	100 mV

Power Supply:	5V _{DC} to 30V _{DC}
Temperature Limits:	
Storage:	– 55°C to +125°C
Operating:	– 40°C to +125°C
Burst Pressure:	1000 psig
Humidity Limit:	0–100% RH
Vibration:	2g from 5 Hz to 500 Hz
Shock:	50g
Case:	Stainless Steel
Wetted Materials:	303 Stainless Steel

Performance Specifications: V₊ = 12V, T_A = 25°C. Specifications are typical unless otherwise noted.

Accuracy ² :	< ±0.30% FS at constant temperature
Non-linearity:	< ±0.10% FS (< ±0.50% FSO max)
Repeatability:	< ±0.20% FS
Thermal Effects ³ : 0°C to +70°C	
Null	0.01 (typ) 0.02 (max) % FS/°C
Span	0.01 (typ) 0.03 (max) % FS/°C
Thermal Effects: – 40°C to 0°C, +70°C to +125°C	
Null	0.02% FS/°C
Span	0.02% FS/°C
Zero Pressure Output:	0 ± 500 μV (max)
Full Scale Output ⁴ :	Nominal ±1mV (max)
Power Consumption:	0.04 Watts
Excitation Voltage:	12 V _{DC} nominal. Any supply voltage between 5 to 30 V _{DC} can be used.
Input Impedance:	4.0kΩ
Output Impedance:	4.0kΩ
Output Noise:	< 0.01% FSO, at 0.1 ≤ f ≤ 1kHz
Response Time:	1.0ms
Offset Stability ⁵ :	± 0.1% FSO
Span Stability ⁵ :	± 0.1% FSO
Common-Mode Voltage ⁶ :	6.0 V _{DC} ± 0.2V

Note 1: For questions regarding media compatibility, please contact the Sensym factory.

Note 2: Accuracy is sum of non-linearity, and repeatability.

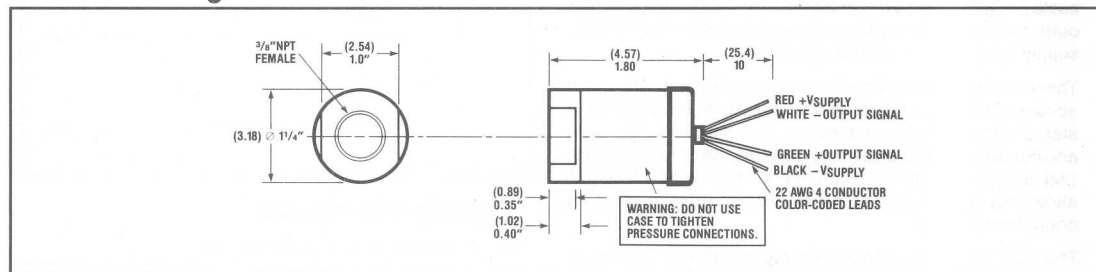
Note 3: Temperature tested and guaranteed at 70°C relative to 25°C. All specifications are shown relative to 25°C.

Note 4: Span guaranteed at 12 V_{DC}. Output is ratiometric to supply voltage.

Note 5: Change in output after 1 year or 1 million pressure cycles.

Note 6: This is the common-mode voltage of the output arms for V_G = 12V_{DC}.

Outline Drawing



WEIGHT:	3 oz. (85.1g)
ELECTRICAL CONNECTION:	4 conductor cable
OPTIONAL MALE PIPE FITTING:	See Section 10

SenSym

ST2000 Series Pressure Transducers 0 to 15 psig to 0 to 500 psig

FEATURES

- High Level Voltage Output
- Field Interchangeable
- Reliable Semiconductor Technology
- Rugged — Stainless Steel
- 0.50% Accuracy
- Low Cost/High Performance
- All Welded Construction

APPLICATIONS

- Energy Management
- Process Control
- Robotics
- Sewage and Water Treatment
- Hydraulics
- Off-Road Vehicles
- Agrionics
- Refrigeration

GENERAL DESCRIPTION

The ST2000 series transducers are fully temperature compensated, signal conditioned transducers that provide a high level voltage output. These rugged stainless steel transducers are designed for the measurement of hostile media in harsh environments. A variety of devices are available from 0 to 15 psig through 0 to 300 psig, and with output voltage options of 1 to 6V_{DC}, or 2.5 to 12.5V_{DC} for each pressure range.

The ST2000 series transducers feature an advanced integrated circuit pressure sensor element which gives excellent accuracy, long term reliability and low cost. Precise laser trimming and factory calibration provides excellent performance over temperature and allows for field interchangeability without calibration. Given the option of a variety of high level output signals, interface to analog-to-digital converters, recorders and other instrumentation is simplified.

The ST2000 series also features a unique diaphragm/oil-fill isolation technique, which minimizes the amount of oil for optimal performance over temperature and also provides the ability to handle extreme burst



pressures. Even upon device failure, the pressure media will be contained up to the burst pressure which typically exceeds normal operating pressure by over 10 times.

Accuracy is guaranteed to be within $\pm 0.5\%$ and all ST2000 series devices feature internal voltage regulation for operation with any supply voltage from 12V_{DC} to 30V_{DC}.⁽¹⁾

The female $\frac{3}{8}$ " NPT for pressure connection accepts a variety of fittings to meet almost any thread requirements, including metric, without unnecessary body length extension. In addition, this rugged package provides excellent resistance to shock and vibration as well as EMI and RFI.

With complete signal conditioning and rugged packaging, the ST2000 series provides high reliability, for use in a wide variety of industrial applications or anywhere harsh or corrosive media are encountered.

PHYSICAL SPECIFICATIONS

ST2000

Media Compatibility

The ST2000 series may be used with any fluid or gas that is compatible with 303 stainless steel.

It should be noted however that the surrounding housing is not hermetically sealed, therefore it is prohibited to submerge the part.

Materials of Construction

Media Wetted Parts:
All stainless steel

Fluid Fill

Dimethylsiloxane

Environmental Protection

The transducer housing is weather resistant and splash proof.

Mass

132 g (4.64 oz.)

FUNCTIONAL SPECIFICATIONS

Service

Service: Liquid, gas or vapor compatible with 303 stainless steel.

Environmental Specifications

Temperature Limits:

Storage: - 55°C to +125°C

Operating: - 40°C to +125°C

Compensated: 0°C to +70°C

Humidity Limits: 0-100% RH

Vibration: 2g's from 5 Hz to 500 Hz

Shock: 50g's

Case: Stainless Steel

Electrical Specifications

Supply Voltage:

Minimum⁽¹⁾ 12V_{DC}

Maximum 30V_{DC}

Reference 15V_{DC}

Output Voltage Options:

1: 1-6V_{DC}

2: 2.5-12.5V_{DC}

Output Current Options:

4: 4-20mA (See ST2000G4 Datasheet)

Pressure Ratings

Part Number	Operating Pressure	Proof ⁽²⁾ Pressure	Burst ⁽³⁾ Pressure
ST2015G	0-15 psig	30 psig	1000 psig
ST2030G	0-30 psig	60 psig	1000 psig
ST2100G	0-100 psig	200 psig	2500 psig
ST2300G	0-300 psig	450 psig	2500 psig
ST2500G	0-500 psig	600 psig	2500 psig

PERFORMANCE SPECIFICATIONS ($T_A = 25^\circ\text{C}$, Common Mode pressure = 0 psig)

ST2000

OUTPUT OPTION 1

($V_{CC} = 15.0\text{V} \pm 5\%$)

Zero Pressure Offset	$1.0\text{V} \pm 100\text{mV (Max)}$
Full Scale Span	$5.0\text{V} \pm 50\text{mV (Max)}$
Full Scale Output	6.0V (Typ)

Thermal Effects⁽⁶⁾

(0 to 70°C)	
Combined Null & Span	$\pm 1.5\% \text{ FS (Max)}$
(-40°C to 0°C , $+70^\circ\text{C}$ to $+125^\circ\text{C}$)	
Combined Null & Span	$\pm 2.0\% \text{ FS (Typ)}$
Non-linearity and Hysteresis	$\pm 0.50\% \text{ FS (Max)}$
Repeatability	$\pm 0.10\% \text{ FS (Typ)}$
Long Term Stability ⁽⁶⁾	$\pm 0.5\% \text{ FS (Typ)}$
Output Noise	$\pm 0.04\% \text{ FS (Typ)}$
Frequency Response	1.0ms (Typ)
(10% to 90%)	
Output Impedance	$< 50\Omega$
Power Consumption	100mW (Typ)
Power Supply Rejection	
Offset	$50 \mu\text{V/V (Typ)}$
SPAN	$.003\% / \text{V (Typ)}$

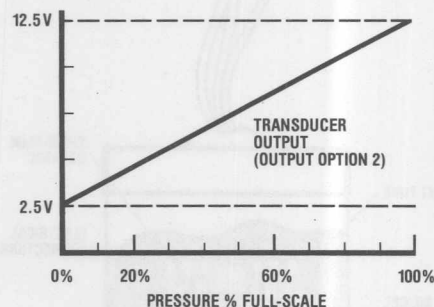
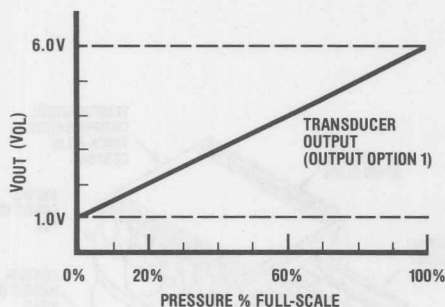
OUTPUT OPTION 2

($V_{CC} = 15.0\text{V} \pm 5\%$)

Zero Pressure Offset	$2.5\text{V} \pm 200\text{mV (Max)}$
Full Scale Span	$10.0\text{V} \pm 200\text{mV (Max)}$
Full Scale Output	12.5V (Typ)

Thermal Effects⁽⁶⁾

(0 to 70°C)	
Combined Null & Span	$\pm 1.5\% \text{ FS (Max)}$
(-40°C to 0°C , $+70^\circ\text{C}$ to $+125^\circ\text{C}$)	
Combined Null & Span	$\pm 2.0\% \text{ FS (Typ)}$
Non-linearity and Hysteresis	$\pm 0.50\% \text{ FS (Max)}$
Repeatability	$\pm 0.10\% \text{ FS (Typ)}$
Long Term Stability ⁽⁶⁾	$\pm 0.5\% \text{ FS (Typ)}$
Output Noise	$\pm 0.04\% \text{ FS (Typ)}$
Frequency Response	1.0ms (Typ)
(10% to 90%)	
Output Impedance	$< 50\Omega$
Power Consumption	100mW (Typ)
Power Supply Rejection	
Offset	$50 \mu\text{V/V (Typ)}$
SPAN	$.003\% / \text{V (Typ)}$



Specification Notes:

- For the 2.5V to 12.5V output option the minimum supply voltage should be 15V.
- Proof pressure is the maximum pressure which may be applied without causing damage to the sensing element.
- The package features a stainless steel diaphragm which is dead ended into a small through hole. The media will therefore be contained until this extreme burst pressure limit is exceeded.
- Reference conditions: Unless otherwise noted supply voltage $V_{CC} = 15\text{V}_{\text{DC}}$, $T_A = 25^\circ\text{C}$, Common mode line pressure = 0 psig.
- Temperature tested and guaranteed from 0°C to 70°C relative to 25°C . All specifications shown are relative to 25°C .
- Change in output after one year or one million pressure cycles.

PHYSICAL CONSTRUCTION

ST2000

General Construction

The ST2000 construction makes use of Sensym's latest integrated circuit pressure sensor in combination with complete signal conditioning circuitry, housed in a rugged stainless steel isolated package (Figures I & II). The temperature compensated sensor along with the signal conditioning PCB is mounted to the hermetically sealed, stainless steel header. Sensym's unique header design utilizes an extremely low volume of silicon oil for the isolating buffer media. This low volume of oil, coupled with the large diaphragm area eliminates temperature errors often associated with isolated sensor technology and provides optimum pressure response.

Package Burst Pressure

Another feature of the ST2000 header is the ability to withstand extreme burst pressure without any transducer leaks or media contamination. Even in the event that an over-pressure destroys the transducer internally, the stainless steel diaphragm will seal the small sensor pressure port resulting in a burst pressure rating which is limited only by the strength of the stainless steel package itself.

Electrical Connection

The header assembly is electrically connected to 22AWG4 conductor cable, and enclosed in a rugged protective stainless steel can. Strain relief provides flexible protection which prevents sharp bends therefore extending the life of the cable.

Environmental Protection

As a final stage in the ST2000 construction, a moisture protective potting material is injected providing excellent long term reliability even in high humidity applications. This constructive technique then results in an extremely rugged and reliable part which can be used with harsh media in the toughest industrial environments.

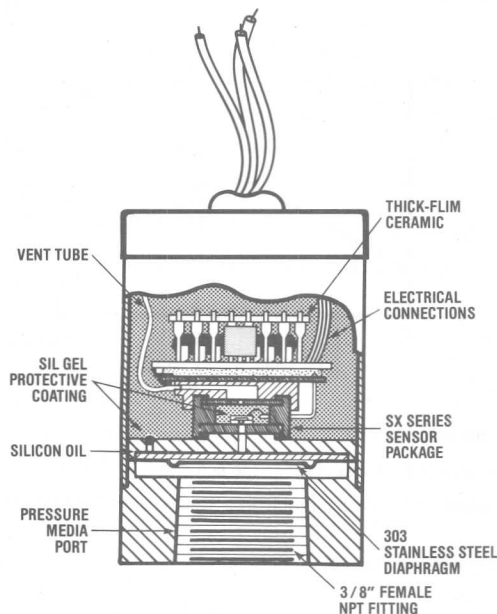


FIGURE I
ST2000 Cross Sectional

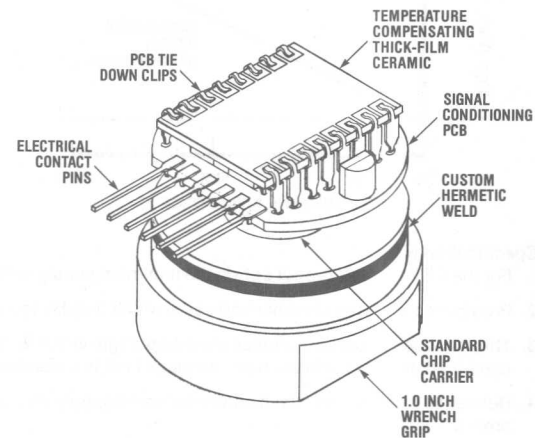


FIGURE II
ST2000 Header

APPLICATION INFORMATION

ST2000

Installation Techniques

The ST2000 provides a versatile $\frac{3}{8}$ " female NPT fitting for pressure connection. This fitting can be used to mount the part directly or it can be used with a variety of male-to-male connectors to provide almost any standard male fitting. Sensym offers two standard fittings described below (also available from Parker Corporation).

Fitting Type	Sensym Part#	Parker Cat. 420 Part#
$\frac{3}{8}$ " NPT to $\frac{1}{4}$ " NPT	SFIT64	6-4MHN
$\frac{3}{8}$ " NPT to $\frac{1}{8}$ " NPT	SFIT62	6-2MHN

In connecting the ST2000 to a fitting or directly to equipment, the wrench flats provided should be used for tightening the transducer. (**Do Not Tighten Using The Can**) See Figure III. The maximum allowable torque for tightening is 30 ft-lbs. Do not over tighten as excess torque can cause shifts in the transducer output.

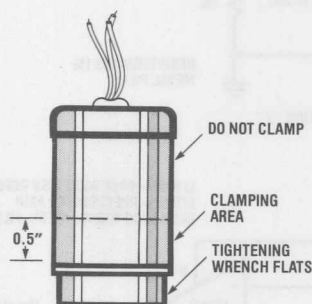


FIGURE III
ST2000 Clamp Area

If the transducer is to be used with flexible tubing it will have to be supported by a bracket and clamped. As shown in Figure IV.

Using this mounting method maintains optimum system rigidity, thus enabling maximum performance from the ST2000 series transducer.

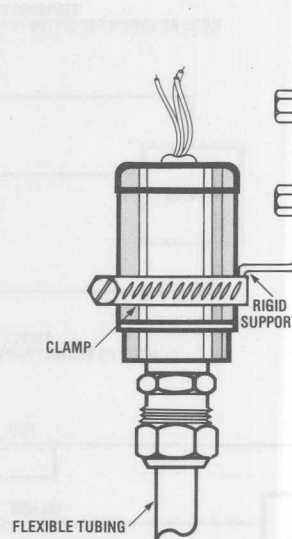
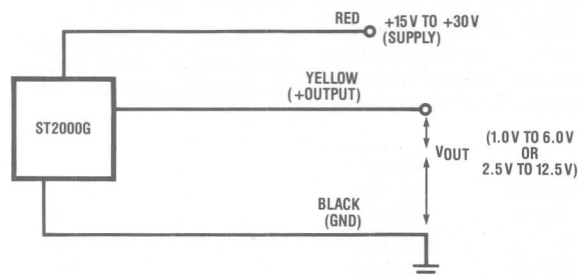
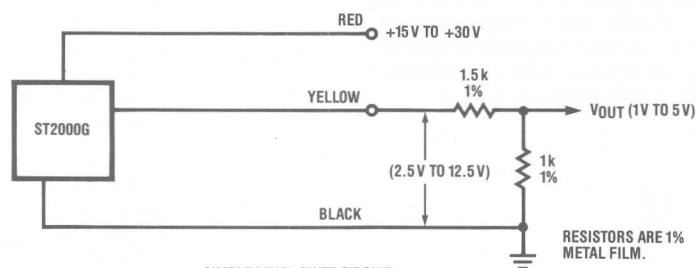


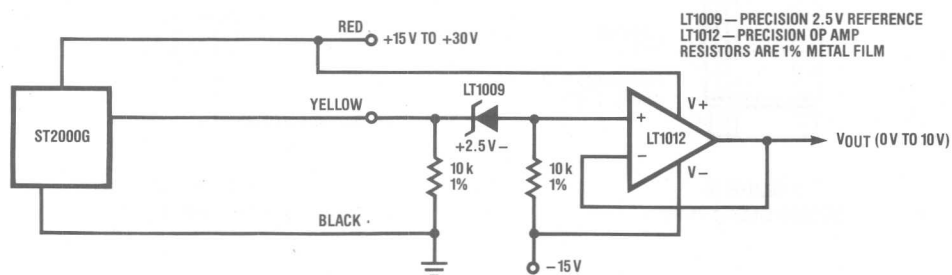
FIGURE IV
ST2000 Rigid Mount



STANDARD ELECTRICAL CONNECTION
NOTE: AS SHOWN FOR OPTION "1" (1.0V TO 6.0V) OR OPTION "2" (2.5 TO 12.5V)



SIMPLE LEVEL SHIFT CIRCUIT.
NOTE: AS SHOWN PROVIDES 1V TO 5V OUTPUT FOR OPTION "2"



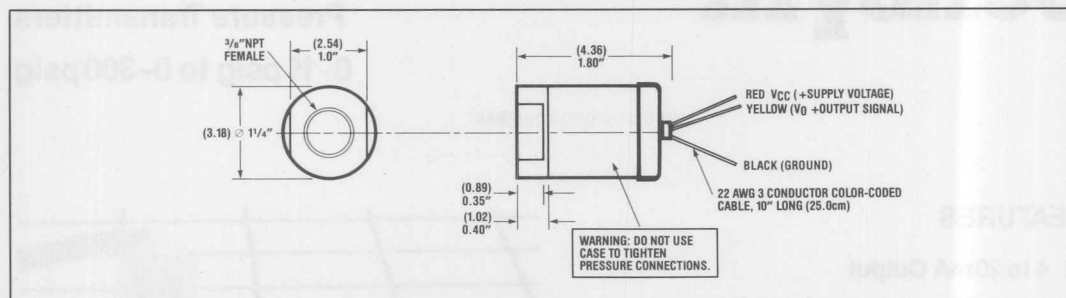
TRUE 0V TO 10V OUTPUT CIRCUIT.
NOTE: AS SHOWN PROVIDES 0V TO 10V OUTPUT USING OPTION "2"

Application Information Notes:

1. To aid in attenuation of spurious noise, power supply decoupling capacitor of 0.1 μ F is contained internally.
2. The black wire and clear wire are internally connected, therefore either wire may be used as ground. It is recommended to short both wires together, or use one on signal ground and one as supply ground.

TRANSDUCER OUTLINE DRAWING

ST2000



WEIGHT: 132 g (4.64 oz.)
ELECTRICAL CONNECTION: 3 conductor cable

TRANSDUCER ORDERING INFORMATION

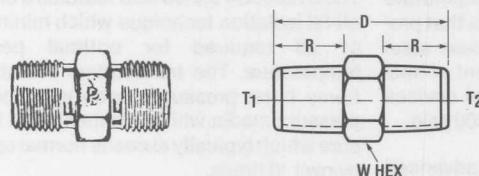
To order, use the following part numbers:

Operating Pressure	Part Numbers for Each Output Option		
	1 to 6 V	2.5 to 12.5 V	4-20 mA
0-15 psig	ST2015G1	ST2015G2	ST2015G4
0-30 psig	ST2030G1	ST2030G2	ST2030G4
0-100 psig	ST2100G1	ST2100G2	ST2100G4
0-300 psig	ST2300G1	ST2300G2	ST2300G4
0-500 psig	ST2500G1	—	ST2500G4

OPTIONAL PIPE FITTING DRAWINGS

Part No.	NPT Thread		W Hex	D		R	
	Male T ₁	Male T ₂		in.	mm	in.	mm
SFIT62	3/8	1/8	3/4	1.27	32.30	0.56/0.38	14.2/9.7
SFIT64	3/8	1/4	3/4	1.45	37.00	0.56	14.2

Male Hex Nipple
MHN



SenSym

ST2000G4 Series Pressure Transmitters 0-15 psig to 0-300 psig

FEATURES

- 4 to 20 mA Output
- Field Interchangeable
- Rugged Stainless Steel
- 0.50% Accuracy
- Low Cost/High Performance
- All Welded Construction

APPLICATIONS

- Energy Management
- Process Control
- Sewage and Water Treatment
- Hydraulics
- Agrionics

GENERAL DESCRIPTION

The ST2000G4 series transmitters are fully temperature compensated, signal conditioned transmitters that provide a 4-20 mA output. These rugged stainless steel transmitters are designed for the measurement of hostile media in harsh environments. A variety of devices are available from 0 to ± 15 psig through 0 to 300 psig.

The ST2000G4 series transducers feature advanced integrated circuit pressure sensor element which gives excellent accuracy, long term reliability and low cost. Precise laser trimming and factory calibration ensures excellent performance over temperature and allows for field interchangeability without recalibration. Accuracy is guaranteed to be within $\pm 0.5\%$ and all ST2000G4 devices feature internal voltage regulation for operation from 12V_{DC} to 36V_{DC}. And, with the two wire 4-20 mA output, remote interfacing is simplified.



The ST2000G4 series also features a unique diaphragm/oil-fill isolation technique which minimizes the amount of oil required for optimal performance over temperature. The transmitters are able to handle extreme burst pressures; even upon device failure, the pressure media will be contained up to the burst pressure which typically exceeds normal operating pressure by over 10 times.

A female $\frac{3}{8}$ " NPT fitting for pressure connection accepts a variety of fittings to meet almost any thread requirements, including metric, without unnecessary body length extension. In addition, this rugged package provides excellent resistance to shock and vibration. With complete signal conditioning and rugged packaging, the ST2000G4 transmitters provide high reliability when used in a variety of industrial applications or wherever harsh or corrosive media are encountered.

FUNCTIONAL SPECIFICATIONS

ST2000G4A

Service

Liquid, gas or vapor compatible with 303 stainless steel.

Environmental Specifications

Temperature Limits

Storage	- 55°C to +100°C
Operating	- 40°C to +100°C
Compensated	0°C to +70°C
Media Temperature	- 40°C to +125°C

Humidity Limits 0-100% RH

Vibration 2g from 5 Hz to 500 Hz

Shock 50g

Case Stainless Steel

Electrical Specifications

Supply Voltage

Minimum ⁽¹⁾	12 V _{DC}
Maximum	36 V _{DC}
Reference	15 V _{DC}

Pressure Ratings

Part Number	Operating Pressure	Proof ² Pressure	Burst ³ Pressure
ST2015G4A	0-15 psig	30 psig	1000 psig
ST2030G4A	0-30 psig	60 psig	1000 psig
ST2100G4A	0-100 psig	200 psig	5000 psig
ST2300G4A	0-300 psig	450 psig	5000 psig

PERFORMANCE SPECIFICATIONS⁴

(T_A = 25°C; V_{CC} = 15.0 V ± 5%)

Characteristic	Min.	Typ.	Max.	Unit
Zero Pressure Offset	—	—	4.0 ± 100 μA	mA
Full-scale Span	—	—	16.0 ± 200 μA	mA
Full-scale Output	—	20.0	—	mA
Thermal Effects ⁵ (0°C to 70°C)				
Combined Null and Span	—	—	± 1.5	% FSO
(- 40°C to 0°C, + 70°C to 100°C)				
Combined Null and Span	—	± 2.0	—	% FSO
Non-Linearity and Hysteresis	—	—	± 0.50	% FSO
Repeatability	—	± 0.10	—	% FSO
Long Term Stability ⁶	—	± 0.5	—	% FSO
Output Noise	—	± 0.04	—	% FSO
Frequency Response (10% to 90%)	—	1.0	—	ms
Power Supply Rejection				
Offset	—	0.005	—	% / V
Span	—	0.003	—	% / V

Specification Notes:

- Note 1:** The minimum supply voltage is directly proportional to the load resistance seen by the transmitter.
- Note 2:** Proof pressure is the maximum pressure which may be applied without causing damage to the sensing element.
- Note 3:** The package features a stainless steel diaphragm which is dead ended into a small through hole. The media will therefore be contained until this extreme burst pressure limit is exceeded.
- Note 4:** Reference conditions: Unless otherwise noted, supply voltage V_{CC} = 15 V_{DC}, T_A = 25°C.
- Note 5:** Temperature tested and guaranteed from 0°C to 70°C relative to 25°C. All specifications shown are relative to 25°C.
- Note 6:** Change in output after one year or one million pressure cycles.
- Note 7:** The package is an all-sealed housing. For proper function, the gage port is vented to the atmosphere through the connecting cable. Thus, the cable end must have an access to the ambient pressure.

PHYSICAL SPECIFICATIONS

ST2000G4A

Media Compatibility

The ST2000G4 series may be used with any fluid or gas that is compatible with 303 stainless steel. The surrounding housing is a drip-and-splash-proof construction.

Fluid Fill

Dimethylsiloxane

Environmental Protection

IP67 according to DIN40050 (locked Connector)⁷

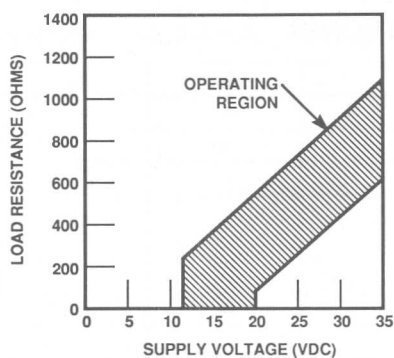
Materials of Construction

Media Wetted Parts:

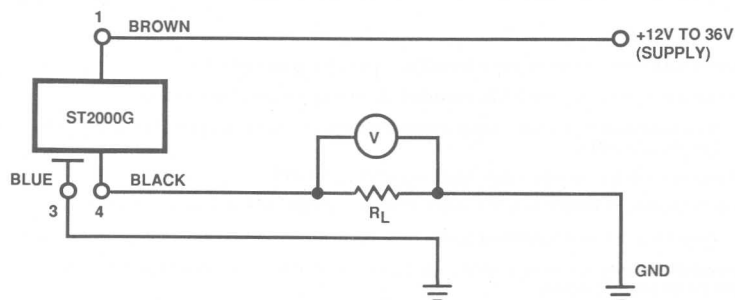
All Stainless Steel (303SS)

Mass

132 g (4.64 oz.)

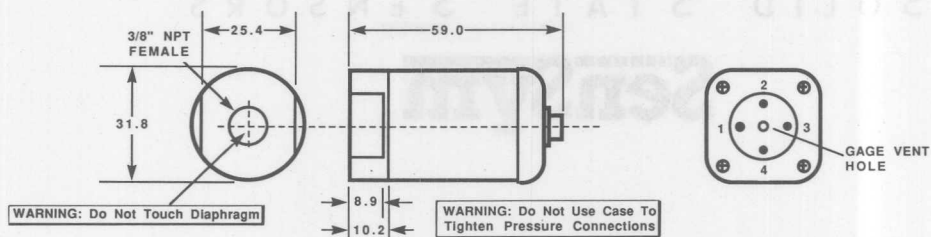


STANDARD ELECTRICAL CONNECTION



TRANSDUCER OUTLINE DRAWING

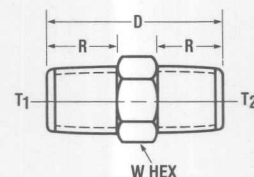
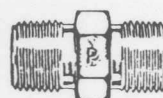
ST2000G4A



OPTIONAL PIPE FITTING DRAWINGS

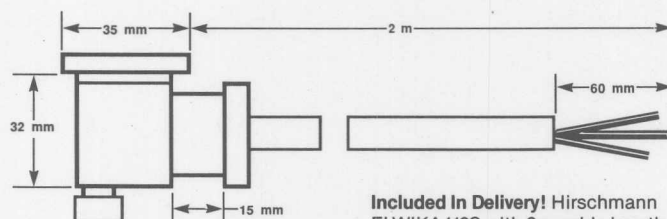
Part No.	NPT Thread		W Hex	D		R	
	Male T ₁	Male T ₂		in.	mm	in.	mm
SFIT62	3/8	1/8	3/4	1.27	32.30	0.56/0.38	14.2/9.7
SFIT64	3/8	1/4	3/4	1.45	37.00	0.56	14.2

Male Hex Nipple
MHN



4

RECOMMENDED CABLE/CONNECTOR ACCESSORY



Included In Delivery! Hirschmann
ELWIKA412S with 2m cable length.
Order part number: ZB09-G4.

Pin Connection

PIN	WIRE
1	Brown
2	White
3	Blue
4	Black

ORDERING INFORMATION

To order, use the following part numbers:

Operating Pressure	Order Part Number
0-15 psig	ST2015G4A
0-30 psig	ST2030G4A
0-100 psig	ST2100G4A
0-300 psig	ST2300G4A

SOLID STATE SENSORS

SenSym

SOLID STATE SENSORS

SenSym

SECTION 5 INSTRUMENTATION-TEST EQUIPMENT

SECTION OF CONTENTS

PDM Series

5-3

SMRT Series

5-5

SOLID STATE SENSORS

SenSym

Sensym

Precision Digital Manometer

200 millibar to 10 bar available in
mmHG, mbar, InWC, and PSI

FEATURES

- True 10,000:1 Dynamic Pressure Range
- Readings Available in mmHG, mBar, InWC, or PSI
- Precision Accuracy
- Easy to Read 3½ Digit Display
- Measures Positive and Negative (Vacuum) Pressure
- 100+ Hour Battery Life
- Two Low Battery Indicators
- Internal Pressure Sensor

APPLICATIONS

- Pneumatic Applications
- Medical Instrumentation Calibration
- HVAC and Flow Monitoring
- Transmitter Servicing
- Laboratory Measurements

GENERAL DESCRIPTION

The PDM Series is comprised of nine standard models of precision digital manometers covering full scale pressure ranges from 20 inches water column (0.7 psi) up through 10 bar (150 psi). Different pressure scales and units of pressure measurement, including PSI, mmHg, and millibars are available to fit a wide variety of applications from industrial pneumatics and HVAC flow to medical equipment and laboratory calibrations. A special industrial transmitter model is available (PDM20PX) which can monitor and display pressure or current as well as acting like a transmitter, outputting 4–20 mA for 3–15 psig or 6–30 psig.

These lightweight, handheld meters have internal pressure sensors and feature shock mounted electronics, industrial rocker switches and a sturdy ABS plastic case for exceptional durability and reliability in tough industrial environments. A chrome-plated locking quick disconnect is provided for pressure connection.

The PDM models offer wide dynamic pressure ranges as they have true high and low pressure ranges. This is not just a change of pressure units but a true change of

the pressure range and resolution. These 3½ digit meters feature 0.05% resolution with 0.50% (± 1 count) accuracy.

All meters are extremely easy to use and maintain as the large 12.7 mm high LCD digits are easy to read, even in direct sunlight. By using low power CMOS circuitry, average battery life is 150 hours. And this is without any battery charging which is difficult to do in the field and is always forgotten about until its time to use the meter. For added safety there are also two low battery indicators. The "Lo Bat" indication on the display comes on when there are 10 hours of battery life remaining and the display reading is still accurate. When the battery drains down such that accuracy is no longer within specification, the display flashes on and off.

All PDM meters come with a compact protective carrying case, a variety of standard pressure and electrical accessories, an operators instruction manual, and pressure conversion slide rule to convert units if necessary. There is a one year unconditional warranty against everything but abuse.



Precision Digital Manometer

PERFORMANCE SPECIFICATIONS (at 25°C)

Accuracy: $\pm 0.50\%$ of Reading or ± 1 count
 Resolution: $\pm 0.05\%$ FS
 Operating Temperature Range: 0–55°C
 Maximum Storage Temperature Range: –40°C to +85°C

Temperature Effects:
 Total Error (0–55°C): $\pm 0.01\%$ FS/°C
 Outside (0–55°C): $\pm 0.02\%$ FS/°C

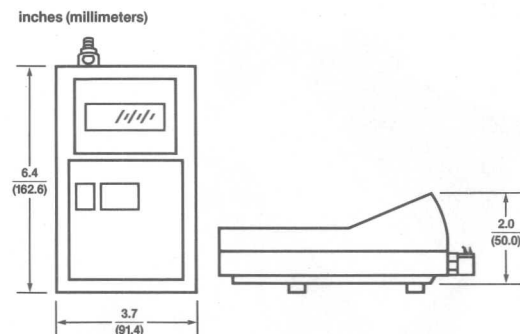
Power Supply:
 Battery: Standard 9V cell
 Typical operating life: 150 hours
 Low Bat indicator at 10 hours operating left
 Flashing display when Low Bat causes system error

Display:
 3½ digit LCD, 12.7 mm (0.5 inch) high black numerals.
 Polarity and Lo Bat indicators.

Pressure Fitting:
 Chrome-plated, locking quick disconnect. (Mating connectors provided.)

Pressure Media:
 Non-corrosive, non-ionic gases and liquids.

PHYSICAL DIMENSIONS



ORDERING INFORMATION To order, use the following model numbers:

MODEL NUMBER	PRESSURE RANGE		RESOLUTION		UNITS (gage)	STANDARD ACCESSORIES Included
	LOW	HIGH	LOW	HIGH		
PDM 10B	NONE	0–10.00	—	0.01	bar	1, 2
PDM100P	NONE	0–100.0	—	0.1	PSI	1, 2
PDM 200B	0–199.9	0–1999	0.1	1.0	millibar	1, 2
PDM 2B	0–1.999	0–10.00	0.001	0.01	bar	1, 2
PDM 200M	0–199.9	0–1000	0.1	1.0	mmHg	1, 2
PDM 20P	0–19.99	0–100.0	0.01	0.1	PSI	1, 2
PDM 200BD*	0–199.9	0–1999	0.1	1.0	millibar (differential)	1, 2
PDM20ID*	0–19.99	0–199.9	0.01	0.1	IN WC (differential)	1, 2

Options:

- 1–Carry Case, Instruction Manual, Pressure Conversion Slide Rule, Screw Driver, Spare Battery
- 2–Pressure connector tubing (3 ft.) and 2 mating quick disconnects
- 3–Mating electrical clip leads

NOTES:

- * Meter offers dual input pressure ports for true differential pressure measurements.

Sensym reserves the right to make changes to any products herein. Sensym does not assume any liability arising out of the application or use of any product or circuit described herein, neither does it convey any license under its patent rights nor the rights of others.

SenSym

SOLID STATE SENSORS

SMRT SERIES 0-1psi to 0-100 psi

PRECISION PRESSURE MONITORING INSTRUMENTS

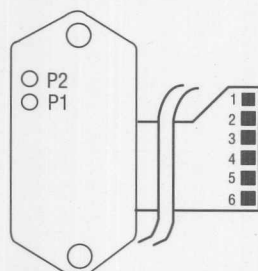
FEATURES

- Direct Digital Output
- Precision Accuracy-
0.5% Max Total Error
- Digitally Compensation

APPLICATIONS

- Barometer
- Medical Equipment
- Industrial Controls
- Precision Lab Equipment

ELECTRICAL CONNECTION



- | | |
|-------------|------------|
| 1) V_{CC} | 4) CLOCK |
| 2) GND | 5) READY |
| 3) DATA | 6) CONVERT |

Note:
Flex circuit Mating Connector:

AMP 520315-6
(without cable retention)

Dupont 68100-906
(with cable retention)

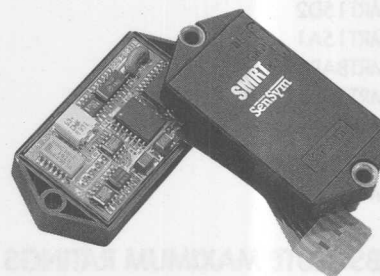
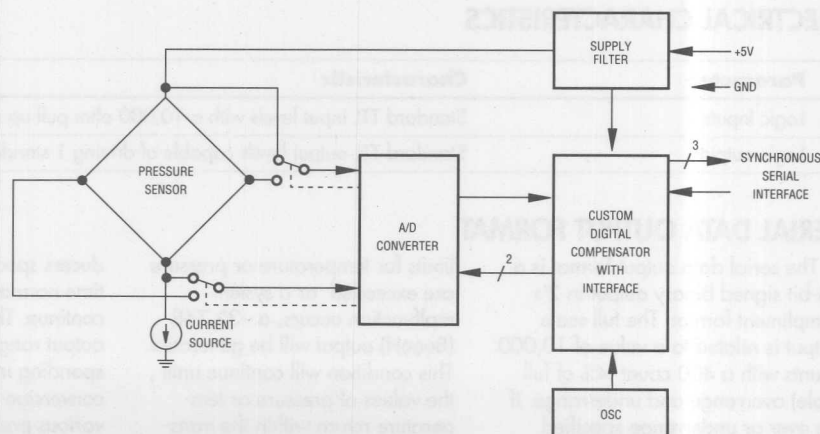
GENERAL DESCRIPTION

The SenSym SMRT series High Precision pressure transducers are low cost digitally compensated pressure transducers. This new compensation technique reduces errors such as pressure nonlinearity and temperature error nonlinearity which typically had to be tolerated and designed around in the past.

Each pressure sensor is now individually characterized over its pressure and temperature range and the resulting data is stored in the microprocessor memory. The stored data represents the ideal transfer curve of that pressure sensor. During normal operation, the microprocessor measures the temperature and pressure sensor output for each reading and looks up the compensated data that has been stored in memory. The result is a pressure transducer with a maximum error (including temperature) of 0.5% of F.S. maximum over a temperature range of -20°C to $+85^{\circ}\text{C}$.

The SMRT precision instruments are available to measure pressures as low as 0 to 1 psi and as high as 0 to 100 psi.

EQUIVALENT CIRCUIT



The transducers are packaged in a thermoplastic nylon housing, providing convenient pressure connection and P.C. board mounting. They are designed for use with non-corrosive gases. For corrosive media applications, SenSym's stainless steel isolated transducers should be used.

PRODUCT SPECIFICATIONS**INDIVIDUAL OPERATING CHARACTERISTICS**

SenSym Part #	Operating Pressure Range	Burst Pressure
SMRT01D1	0-1 psid	10 psig
SMRT01D2	±1 psid	10 psig
SMRT05D1	0-5 psid	20 psig
SMRT05D2	± 5 psid	20 psig
SMRT15D1	0-15 psid	45 psig
SMRT15D2	± 15 psid	45 psig
SMRT15A1	0-15 psia	45 psia
SMRTBAR01	20-32 in Hg (Abs)	75 in Hg (Abs)
SMRT30D1	0-30 psid	60 psig
SMRT30A1	0-30 psia	60 psia
SMRT100D1	0-100 psid	150 psig
SMRT100A1	0-100 psia	150 psia

ABSOLUTE MAXIMUM RATINGS

Ambient Temperature Under Bias	-40°C to +95°C
Storage Temperature	-40°C to +105°C
Supply Voltage (V_{CC})	7V _{DC}
Voltage on Any Pin with Respect to Gnd	-0.6V to $V_{CC}+0.6V$

OPERATING CONDITIONS

Compensated Temperature Range	-20°C to +85°C
Supply Voltage (V_{CC})	+4.75V _{DC} to +5.25V _{DC}
Supply Current	8mA typ, 12mA max

REFERENCE CONDITIONS

Supply Voltage	5.0V _{DC}
Reference Temperature	-20 to +85°C
Common-mode Pressure	0 psig

ELECTRICAL CHARACTERISTICS

Parameter	Characteristic
Logic Inputs	Standard TTL input levels with a 10,000 ohm pull up resistor to V_{CC} .
Logic outputs	Standard TTL output levels capable of driving 1 standard LS load.

SERIAL DATA OUTPUT FORMAT

The serial data output format is a 16-bit signed binary output in 2's compliment format. The full scale output is related to a value of 10,000 counts with a 400 count (4% of full scale) overrange and underrange. If the over or underrange specified

limits for temperature or pressure are exceeded or a system malfunction occurs, a -32,768 (8000H) output will be generated. This condition will continue until the values of pressure or temperature return within the trans-

ducers specified ranges. At this time normal operation will continue. The table presents output ranges with their corresponding input ranges and conversion multipliers for the various pressure units.

PERFORMANCE CHARACTERISTICS ⁽¹⁾

(All devices except SMRTBAR01.)

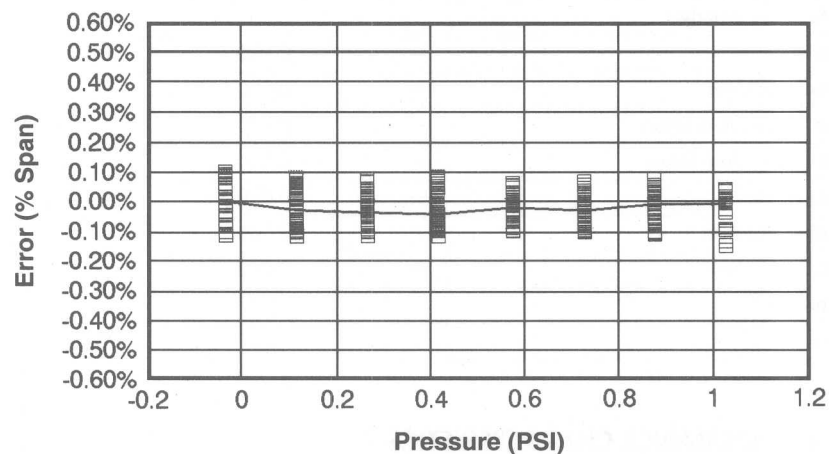
Parameter	Min.	Typ.	Max.	Units
Overall Accuracy ⁽²⁾	—	0.2	0.5	% FSO
Overall Accuracy Includes:				
Linearity	—	0.010	—	% FSO
Pressure Hysteresis	—	0.020	—	% FSO
Offset Temperature Errors	—	0.070	—	% FSO
Span Temperature Errors	—	0.020	—	% FSO
Repeatability	—	0.010	—	% FSO
Offset Calibration	—	0.040	—	% FSO
Span Calibration	—	0.030	—	% FSO
Long Term Stability ⁽³⁾	—	0.1	—	% FSO
Response Time	—	60	80	ms

SMRTBAR01 PERFORMANCE CHARACTERISTICS ⁽¹⁾

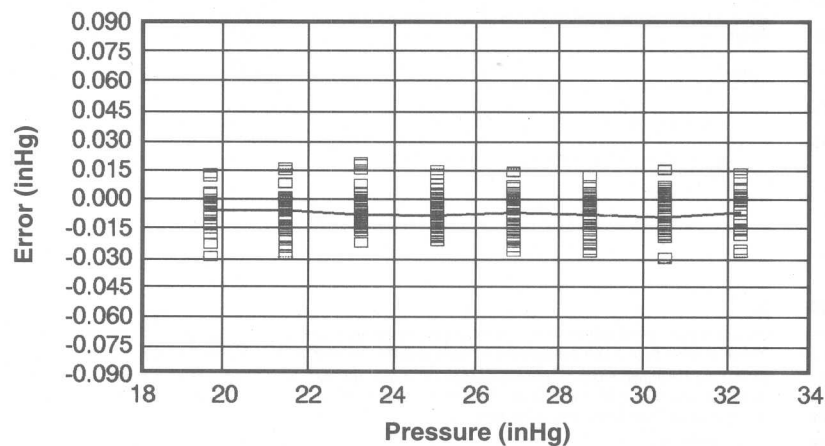
Parameter	Min.	Typ.	Max.	Units
Overall Accuracy ⁽²⁾	—	0.030	0.075	inHg
Overall Accuracy Includes:				
Linearity	—	0.0060	—	inHg
Pressure Hysteresis	—	0.0075	—	inHg
Offset Temperature Errors	—	0.0114	—	inHg
Span Temperature Errors	—	0.0232	—	inHg
Repeatability	—	0.0050	—	inHg
Offset Calibration	—	0.0003	—	inHg
Span Calibration	—	0.0025	—	inHg
Long Term Stability ⁽³⁾	—	0.010	—	inHg
Response Time	—	60	80	ms

SPECIFICATION NOTES:

- Note 1: Performance specifications shown are at reference conditions, pressure applied to port P2. For gage and differential, absolute pressure applied to P₁, P₂ blocked. For operation at other than 5.0V, the typical change in output is less than 0.1% FSO from +4.75V_{DC} to +5.25V_{DC}.
- Note 2: Overall accuracy includes the combined effects of offset and span shifts over temperature, linearity, hysteresis, and offset and span calibration. Note, digital resolution is 0.03% FSO. Some of the typical specifications for the components of overall accuracy are based on statistical averages which may in some cases exceed system resolution.
- Note 3: Long term stability over a twelve month period.

APPLICATION INFORMATION**TYPICAL SMRT CALIBRATION DATA**
Error Over Calibrated Pres. & Temp.

□ All Temp. Data
— Ambient Temp.

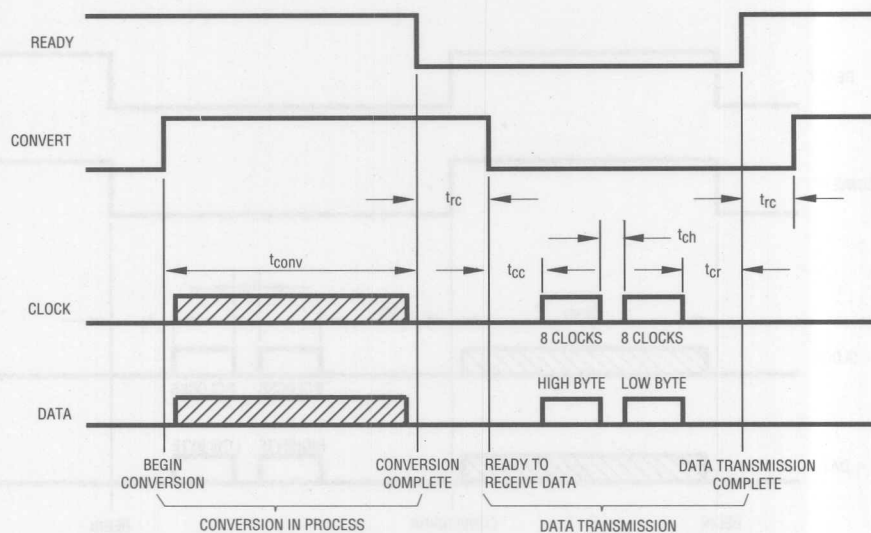
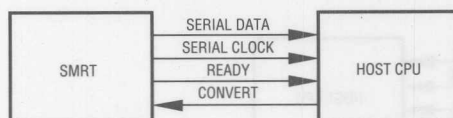
TYPICAL SMRT-BAR01 CALIBRATION DATA
Error Over Calibrated Pres. & Temp.

□ All Temp. Data
— Ambient Temp.

APPLICATION INFORMATION

SMRT SERIAL INTERFACE

Handshake Mode



5

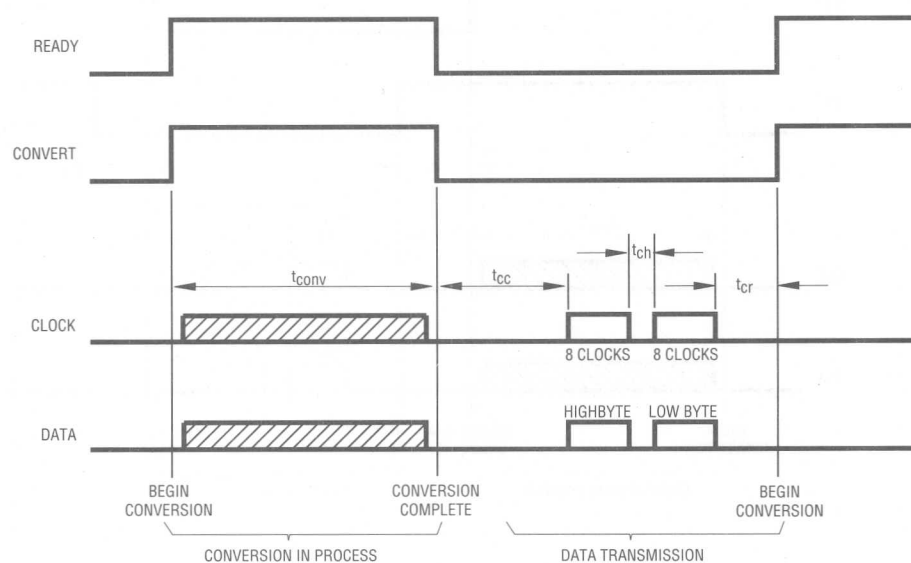
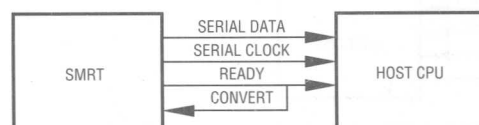
TIMING CHARACTERISTICS

Symbol	Parameter	Min	Typ	Max	Units
t_{conv}	Conversion Time	—	60	80	ms
t_{rc}	Ready to Convert	0	—	—	μ s
t_{cc}	Convert to Clock Delay	24	—	39	μ s
t_{ch}	Clock Hold-off Between Bytes	—	57	—	μ s
t_{cr}	Clock to Ready Delay	—	14	—	μ s
t_{bit}	Serial Data Bit Time	—	16	—	μ s
t_{ckh}	Serial Data Clock High Times	—	8	—	μ s
t_{dsu}	Serial Data Set-up Time	—	3	—	μ s
t_{dh}	Serial Data Hold Time	—	11	—	μ s

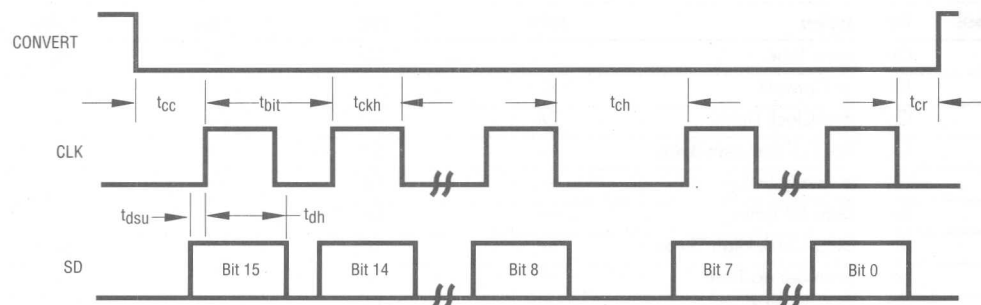
APPLICATION INFORMATION

SMRT SERIAL INTERFACE

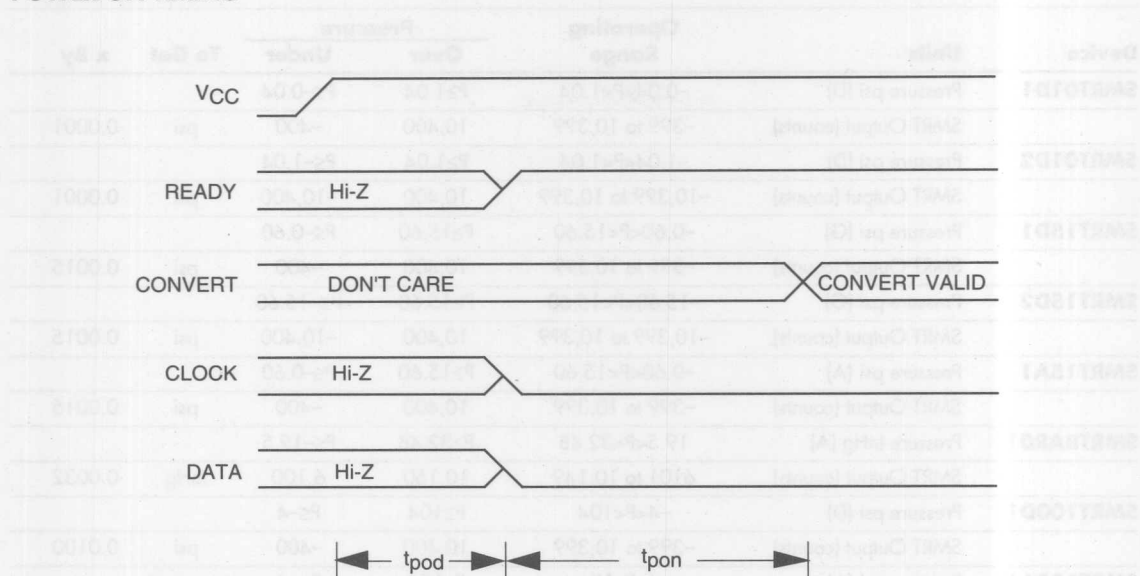
Free Running Mode



DATA TRANSFER TIMING DIAGRAM



POWER ON TIMING



5

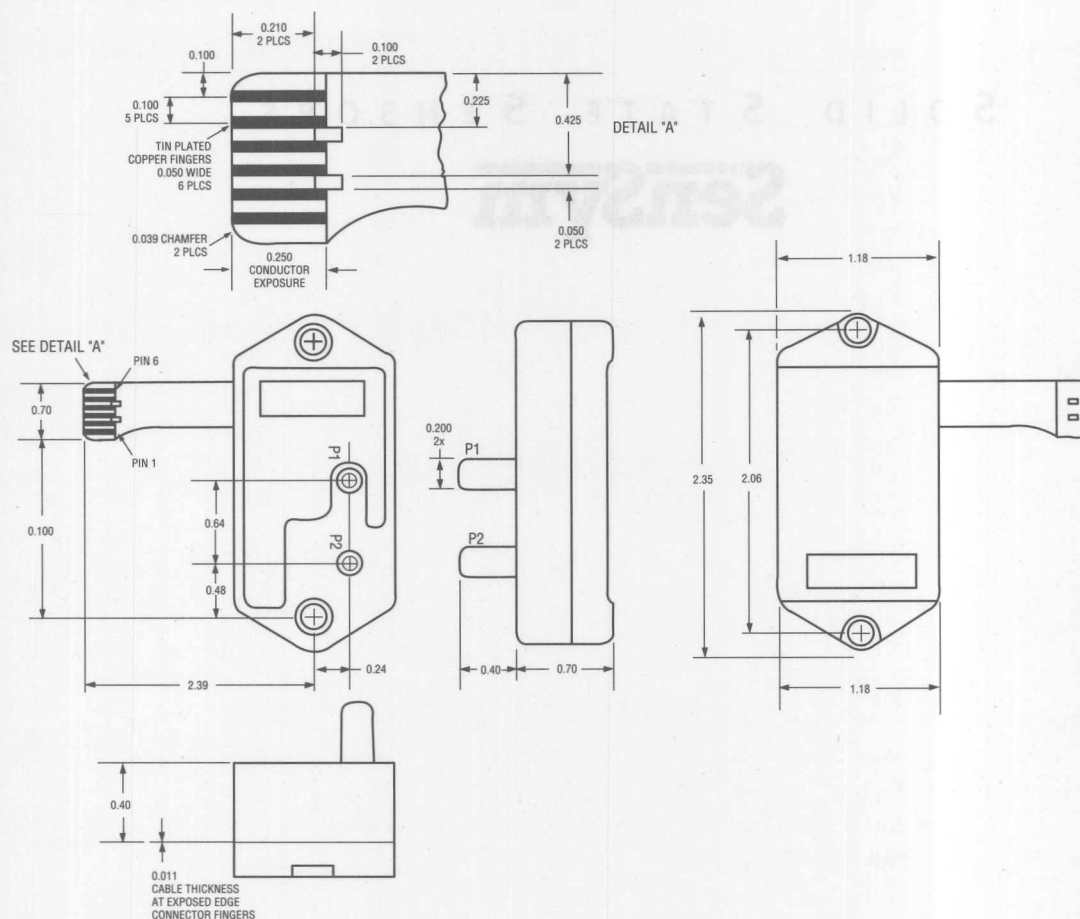
POWER ON TIMING

Symbol	Description	Min.	Typ	Max	Units
t_{pod}	Power-On Delay	8	—	32	ms
t_{pon}	Power-On Start-Up	—	50	—	ms

Note: At the end of the warm-up period, the convert input signal will be assumed valid and normal operation will begin.

Device	Units	Operating Range	Pressure		To Get	x By
			Over	Under		
SMRT01D1	Pressure psi (D)	-0.04<P<1.04	P≥1.04	P≤-0.04		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0001
SMRT01D2	Pressure psi (D)	-1.04<P<1.04	P≥1.04	P≤-1.04		
	SMRT Output (counts)	-10,399 to 10,399	10,400	-10,400	psi	0.0001
SMRT15D1	Pressure psi (G)	-0.60<P<15.60	P≥15.60	P≤-0.60		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0015
SMRT15D2	Pressure psi (G)	-15.60<P<15.60	P≥15.60	P≤-15.60		
	SMRT Output (counts)	-10,399 to 10,399	10,400	-10,400	psi	0.0015
SMRT15A1	Pressure psi (A)	-0.60<P<15.60	P≥15.60	P≤-0.60		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0015
SMRTBAR01	Pressure InHg (A)	19.5<P<32.48	P≥32.48	P≤-19.5		
	SMRT Output (counts)	6101 to 10,149	10,150	6,100	InHg	0.0032
SMRT100D1	Pressure psi (D)	-4<P<104	P≥104	P≤-4		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0100
SMRT100A1	Pressure psi (A)	-4<P<104	P≥104	P≤-4		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0100
SMRT05D1	Pressure psi (D)	-0.20<P<5.20	P≥5.20	P≤-0.20		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0005
SMRT05D2	Pressure psi (D)	-5.20<P<5.20	P≥5.20	P≤-5.20		
	SMRT Output (counts)	-10,399 to 10,399	10,400	-10,400	psi	0.0005
SMRT30D1	Pressure psi (D)	-1.20<P<31.20	P≥31.20	P≤-1.20		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0030
SMRT30A1	Pressure psi (A)	-1.20<P<31.20	P≥31.20	P≤-1.20		
	SMRT Output (counts)	-399 to 10,399	10,400	-400	psi	0.0030

PHYSICAL DIMENSIONS



5

ORDERING INFORMATION

SenSym Part #	Operating Pressue Range
SMRT01D1	0-1 psid (g)
SMRT01D2	±1 psid (g)
SMRT05DI	0-5 psid (g)
SMRT05D2	±5 psid (g)
SMRTBAR01	20-32 In. Hg
SMRT15D1	0-15 psid (g)
SMRT15D2	±15 psid (g)
SMRT15A1	0-15 psia
SMRT30D1	0-30 psid
SMRT30A1	0-30 psia
SMRT100D1	0-100 psid (g)
SMRT100A1	0-100 psia

SOLID STATE SENSORS

SenSym

SOLID STATE SENSORS



SECTION 6

EVALUATION BOARDS

SECTION TABLE OF CONTENTS

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SCX-PRL8	6-13
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SMRT-EB	6-27
SenSym's Evaluation Board Order Form	6-34

SOLID STATE SENSORS

SenSym

FEATURES

- Selectable Voltage Outputs
- Single or Dual Supply Operation
- Pressure from 0-1 to 0-100 psi
- Instant Prototyping

INTRODUCTION

The SCX-EB universal evaluation board has been designed for use with SenSym's SCX and SSX series of pressure sensors to facilitate the breadboarding of virtually any application that involves pressure sensing. By simply calculating a single resistor value to set the amplifier gain and understanding the use of the jumper connections, the board should be ready for total circuit evaluation in less than 30 minutes. A general circuit description and several design examples are presented.

GENERAL DISCUSSION

Referring to the schematic diagram shown in Figure 1, amplifier A1 is used to provide a regulated voltage for the SCX sensor. In this manner, the circuit becomes independent of supply variations, power supply noise and ripple. The voltage, V_B , at test point one (TP1) will be 10V when jumper J4 is left open, and V_B will be at 5V when J4 is connected.

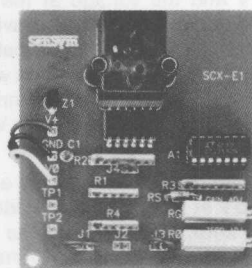
Amplifiers A3 and A4 are connected as an instrumentation amplifier and provide gain to the input signal, V_{IN} . A detailed description of this particular instrumentation amplifier configuration can be found in Sensym application Notes 17 and 18, so a rigorous mathematical derivation will be avoided and only final design equations will be presented here.

Amplifier A2, in conjunction with potentiometer R_O set the initial (zero-pressure) output voltage. The complete expression for the output voltage, V_O , is given by the following equation:

$$V_O = V_{IN} \left[2 \left(1 + \frac{R_3}{R_T} \right) \right] + V_R$$

where $R_T = R_S + R_G$
and V_R is the voltage at TP2 as set by R_O .

Connection point $V -$ can be connected to a negative power supply when available. The connection to $V -$ allows the evaluation board to run from dual supplies,



thus giving the output the ability to swing to or below true ground. When a negative power supply is not used, the output of the evaluation board at zero pressure will be 50 to 150 mV above ground. This small offset voltage can be suppressed by mounting a 2.0 k Ω resistor, R5, on the output stage of the evaluation board. When R5 is in place the zero pressure offset can be reduced to 30 to 80 mV above ground. Also, when a negative power supply is not used, jumper J5 must be included such that $V -$ will be eliminated from operation. When jumper J5 is connected, $V -$ will be connected to ground.

The polarity shown for the output voltage of the SCX Sensor assumes that the pressure is applied to port B. By using jumpers J1, J2, and J3, a variety of combinations are possible for V_R , the output voltage that is to represent zero pressure. For example, it is possible to set the output voltage to change from 1.00 V at zero pressure to 5.0 V at full-scale pressure; or if dual supplies are available, to set the output at 0V at zero pressure and 5.0V at full-scale positive pressure and -5.0V for an equal but negative pressure (vacuum). Also, by using the proper jumper connections, at zero pressure the output could be set to 5.0V with swings to +10 for positive pressure and to ground for negative pressure. These, as well as many other combinations, are possible.

POWER SUPPLY OPTIONS

The evaluation board can be operated from single or dual power supplies. In either case certain voltage limitations do exist.

- (A) Single Supply Operation. The SCX evaluation board requires a supply voltage of 8 to 30V for correct operation.
- (B) Dual Supply Operation. When the SCX evaluation board is powered by dual supplies, the positive power supply must be between 8 and 30V, while the negative voltage supply can be any negative voltage down to -22V. However, the total voltage across the board must be limited to 30V.

JUMPER CONNECTIONS

- (A) Jumper J4. This jumper simply controls the non-inverting gain of amplifier A1. With J4 open, the gain is $4V/V$ and the voltage at the top of the bridge will be approximately $10V$. Leaving J4 open is the proper connection for all applications where V_+ is $12V$ or higher. For applications where V_+ is between $8V$ and $12V$, J4 should be connected. This will give A1 a gain of $2V/V$ and hence V_B will be at approximately $5V$.
- (B) Jumpers J1 and J2. This network is a voltage divider, with $2.5V$ at the top of the divider. Since $R1$ and $R0$ are $10k\Omega$, the range of the wiper arm voltage is easy to determine. With Jumpers J1 and J2 open, the wiper arm will range from $0.83V$ to $1.67V$ and hence, this is also the range of adjustment for voltage V_R at TP2 (assuming Jumper J3 is open). If J1 is shorted, the range of adjustment is now from $1.25V$ to $2.5V$. If J2 is shorted and J1 left open, the range is from approximately $0.0V$ to $1.25V$.
- (C) Jumper J3. With jumper J3 open, the gain of A2 is unity. With J3 shorted, the gain is $3V/V$. This jumper is only useful when it is desired to set V_R higher than $2.5V$, which is the maximum possible by using only J1 and J2. For example, if it is required to set V_R between $3.75V$ and $7.5V$, the

best adjustment is accomplished by jumpering J1 and J3. If it desired to set V_R at (or near) ground, jumpers J1 and J3 should be left open and J2 should be shorted.

- (D) Jumper J5. This jumper is used when operation is from a single supply. When a negative power supply is not used, jumper J5 must be included such that V₋ will be eliminated from operation. When jumper J5 is connected, V₋ will be connected to ground.
- (E) Jumpers J6 and J7. These jumpers will only be used when an SCX absolute sensor is used on the evaluation board. The absolute sensors have reversed output terminals compared to the differential/gauge SCX devices. When differential/gauge parts are used, jumpers J6 and J7 are not connected and, on the solder side of the evaluation boards, jumper points P1 and P2 are soldered.

When using an SCX gauge or differential sensor:

P_1 and P_2 are shorted, and J_6 and J_7 are left open.

But, when an absolute sensor is used:

P_1 and P_2 are left open and, J_6 and J_7 are shorted.

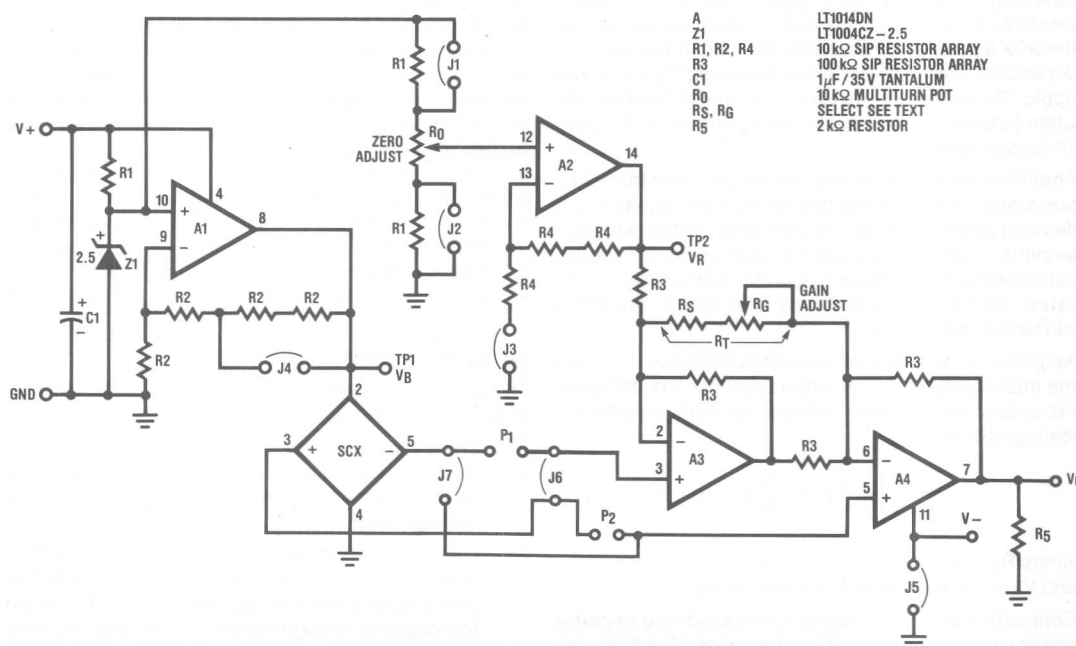


FIGURE I Schematic Diagram

DESIGN EXAMPLES

Example 1:

Consider the need to measure a positive pressure from 0 to 100psi and provide a 1V to 6V output, given a 15V supply.

Solution: since a 15V supply is available, J4 will be left open which will provide 10V to the sensor. From the SCX100DNC data sheet, the output span for 100psi input pressure is 100mV *when operating from a 12V supply*. Because the span is ratiometric to the supply voltage, the output for a 10V supply will be 83.33mV. Since the output span desired is 5V (from 1V to 6V), the voltage gain required is 60V/V. From equation (1),

$$A_v = \frac{\Delta V_O}{\Delta V_{IN}} = 2 \left[1 + \frac{R_3}{R_T} \right]$$

For $R_3 = 100k\Omega$, this equation is then solved for $R_T = 3.448k\Omega$. For the best adjustment range, we will select $R_S = 3.24k\Omega$ and R_G to be a 500 Ω multiturn cermet pot.

Since the zero pressure output voltage, V_R , is to be 1.0V, this is easily accommodated by leaving all jumpers open except jumper J5 which is shorted. R5 is not connected. The final circuit design is shown in Figure 2.

ADJUSTMENT PROCEDURE

- With zero pressure applied, adjust R_O until V_O is 1.00V.
- Apply 100psig and adjust R_G until the output is 6.00V.
- Repeat (a) and (b), if required.

Example 2:

A dialysis machine must measure a pressure of ± 500 mmHg. It is desired that the output voltage be nominally at 5.00V and provide an output change of ± 2.5 V for this pressure input. A +12V supply is available.

Solution: Again, J4 will be left open to provide 10V to the top of the SCX sensor. We will select an SCX15DNC for this application. From the SCX15DNC data sheet, the span at 12V supply and 15psi is 90mV. This equates to 0.5mV/V, per psi. Thus, at 10V and 500mmHg (9.67psi) the output from the bridge will be 48.35mV. Because it is required that a 500mmHg pressure provide an output voltage change of 2.5V, the gain required is 51.7V/V. Again, using the gain equation and solving for R_T , R_T is found to be 4.024k Ω . To allow for approximately $\pm 5\%$ gain adjustment from nominal, choose $R_S = 3.74k\Omega$ and R_G to be a 500 Ω multiturn pot.

Since the zero pressure output required is 5.00V, jumpers J1, J3, and J5 will be connected and jumpers J2, J4, J6, J7 are left open. R5 is not connected. In this manner, the wiper arm voltage of R_O can range from 1.25V to 2.5V and amplifier A2 provides a gain of 3V/V. Thus, V_R can be adjusted from 3.75V to 7.5V. The ad-

justment method is identical to that given in Example 1. Figure 3 shows the circuit schematic for this example.

Example 3:

It is desired to replace an existing sensor that provides an output of 1.0V at zero pressure, and 6.0V at 5psig. The only power supply readily available is the +8V supply used in the original design.

Solution: Because the power supply is 8V, jumper J4 is connected to operate the sensor at 5V. The SCX05DNC is selected, which at 12V will provide an output of 60mV at 5psi. Thus, with a 5V supply, the output will be 25mV at 5psi. Since the span required at the amplifier output is 5V, the gain required is 200V/V. Again, solving for R_T using the gain equation, R_T is found to be 1.01k Ω and we will select $R_S = 909\Omega$ and R_G to be a 200 Ω pot. Since the output for zero pressure is to be 1.00V, this can be achieved by leaving all jumpers open except J5 and J4, which are shorted. The circuit is shown in Figure 4. The adjustment procedure is as given in Example (1) and may require two or three iterations due to the high gain.

Example 4:

A machine used for "picking and placing" electrical components for PC board mounting uses a vacuum line to pick up the component. It is desired to monitor the vacuum line to ensure the component is picked up. With air flowing through the small orifice, at the head of the picker, a small vacuum of 13psia (-2 psig) is expected. With a component securely attached, the vacuum will go to 6psia (-9 psig). Because the output signal goes to the input of a standard 5V logic gate, it is desirable that the -2 psig pressure be represented by +5V and at a pressure of -9 psig the output should be near ground to represent a low logic level. A +12V supply is available.

Solution: In this application, linearity is not critical. Although the actual pressure change to be measured is 7psig, we will select the SCX05DNC which will provide adequate sensitivity but at the same time not be too sensitive such that a component that is only partially held would go undetected. Again, J4 is left open to provide 10V to the SCX sensor. Since the SCX05DNC provides an output of 1mV/V per psi, the output of the sensor for a pressure change of 7psi (when operating from a 10V supply) will be a change of 70mV. To provide an output swing of 5V, a gain of about 70V/V is now required. Solving for R_T , R_T is found to be 2.94k Ω . Because the gain is not critical, we can select R_S to be 2.94k Ω and not use pot R_G . A piece of wire must be used in place of R_G by shorting both ends of the pot together. These points are easily located by looking at the evaluation board layout. To be able to set the output at 5.0V, jumpers J1, J3, and J5, should be used. Jumpers J4, J6, J7, and R5 are not attached. Figure 5 shows the final design.

ADJUSTMENT PROCEDURE

There are two methods to adjust this circuit.

If the vacuum pump is turned on, simply adjust R_0 until the output is at 5.0V when the picker does not have a component attached. If the pump is not turned on, adjust R_0 until the output is at 6.2V. This is equivalent to offsetting the output by a pressure that is 1.7 psig higher than the actual expected operating pressure of 13 psia. This is done because, with no vacuum pump, the sensor will be measuring the ambient pressure of about 14.7 psia. This fact also points out that there may be a need to clamp the output voltage to 5V if the logic gate cannot tolerate a 6.2V input if the pump is not on or should fail.

We are particularly proud of the SCX family and we hope this brief technical explanation will help you in the evaluation of the SCX product family. To this end, Figure 6 is provided to aid you with your design.

If you have any questions about this product, your particular application, or any other Sensym product, please call us. We are always happy to assist you in any way we can.

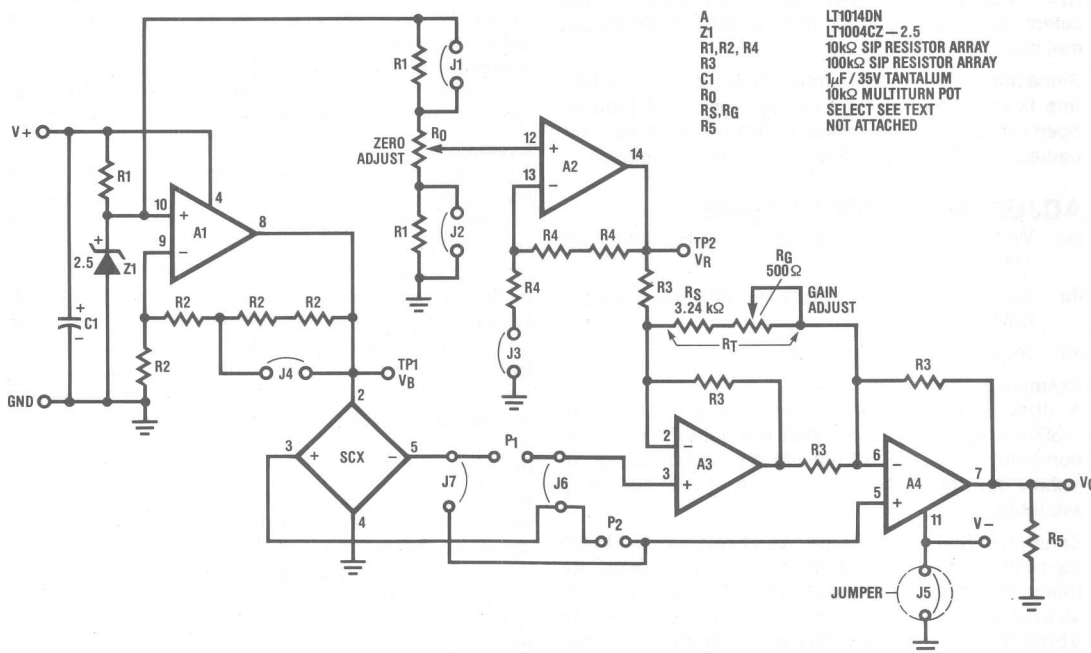


FIGURE II 1V to 6V Output for 0-to-100 psi Input

SCX Evaluation Board

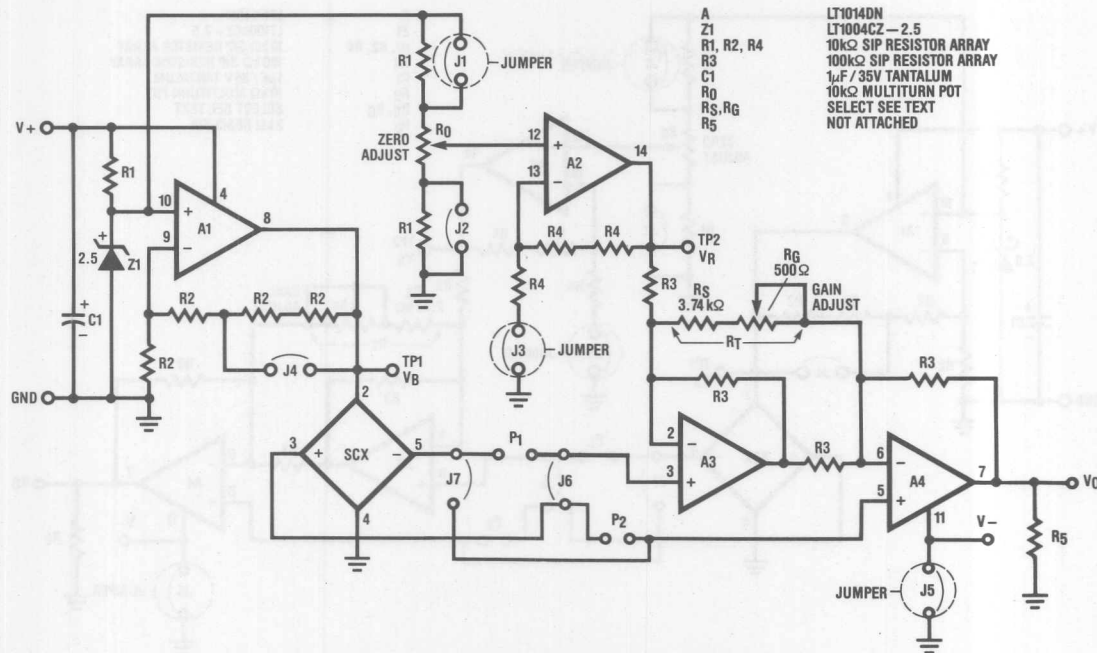


FIGURE III 5V ±2.5V Output for ±500 mmHg Input

6

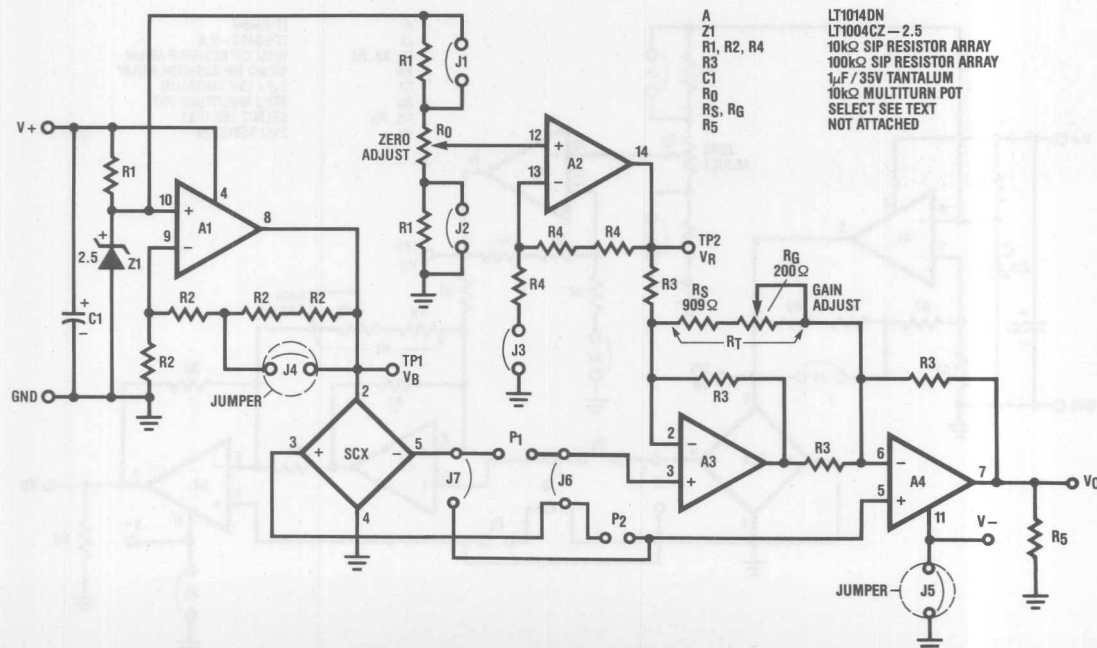


FIGURE IV 1V to 6V Output for 0-to-5 psi Input

SCX Evaluation Board

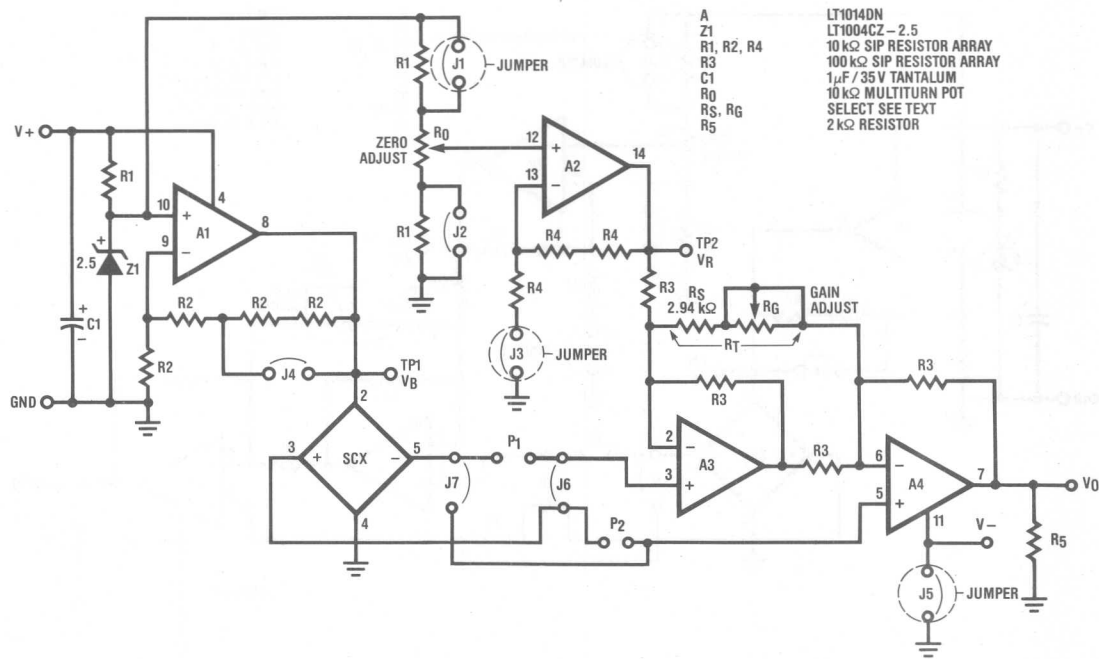


FIGURE V 0V to 5V Output for Vacuum Sensing

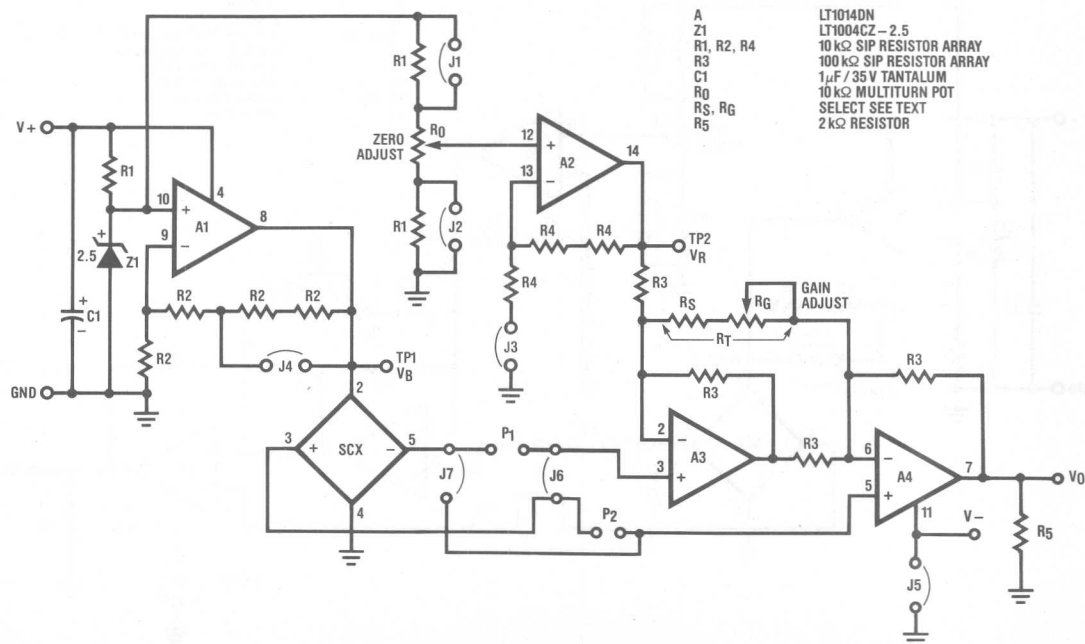
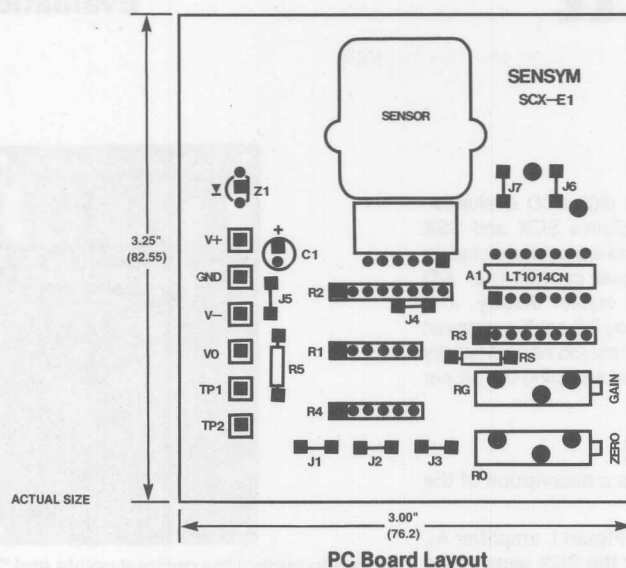


FIGURE VI Your Design Goes Here

PHYSICAL DIMENSIONS

SCX Evaluation Board



ORDERING INFORMATION

To order evaluation boards, complete the form shown on the back page. Evaluation boards are available for all standard SCX Series devices shown below. For other

pressure ranges, please contact the Sensym factory. Each evaluation board includes the PC board with all components, including the SCX "C" series sensor pre-assembled and ready to use.

6

STANDARD PRESSURE RANGES

Part Number	Operating Pressure	Proof Pressure*
SCX01DNC	0 - 1 psid	20 psid
SCX05DNC	0 - 5 psid	20 psid
SCX15ANC	0 - 15 psia	30 psia
SCX15DNC	0 - 15 psid	30 psid
SCX30ANC	0 - 30 psia	60 psia
SCX30DNC	0 - 30 psid	60 psid
SCX100ANC	0 - 100 psia	150 psia
SCX100DNC	0 - 100 psid	150 psid
SCX150ANC	0 - 150 psia	150 psia
SCX150DNC	0 - 150 psid	150 psid

* Maximum pressure above which causes permanent sensor failure.

Other Evaluation Boards

SenSym also offers a complete family of evaluation boards for the SCX and SSX Series pressure sensors. These include output option for 8-bit serial, 8-bit parallel, 3½ digit LCD, 4½ digit and 4-20mA. For further information on these products, contact your local SenSym representative or call directly to the SenSym factory.

INTRODUCTION

The SCX-LCD is a complete 3½ digit LCD evaluation board designed for use with SenSym's SCX and SSX Series Sensors. This evaluation board is provided complete with the SCX sensor, analog signal conditioning, A/D converter, and a 3½ digit liquid crystal display. The evaluation board can be set to display full-scale pressures from below 1 psi (70 mbar) up to 500 psi (35 bar), simply by calculating a single gain resistor and selecting the proper jumpers.

GENERAL DISCUSSION

The following discussion provides a description of the board circuitry and layout.

Voltage Regulator— Referring to Figure 1, amplifier A₁, provides a regulated 5V to power the SCX sensor and ICL7106. This internal regulator allows the circuit to operate from supply voltages ranging from 7 to 30V_{DC} without excessive errors or current drain. With this internally regulated 5V supply, the circuit will only draw approximately 4mA. This then gives a battery life of over 100 hours for a typical 9V alkaline battery. Also, as configured here, the low battery indicator will be displayed when the supply voltage is less than 7V.

Sensor Amplifier— To provide gain to the sensor output, amplifiers A₂, A₃, and A₄ are connected as a quasi-instrumentation amplifier. In addition, amplifier A₄ is used to provide an offset (zero pressure) adjust which does not load the basic sensor. The gain equation for this complete amplifier configuration is:

$$A_v = \frac{V_o}{V_{in}} = \left[2 \left(1 + \frac{R_{10}}{R_T} \right) \right] \quad (1)$$

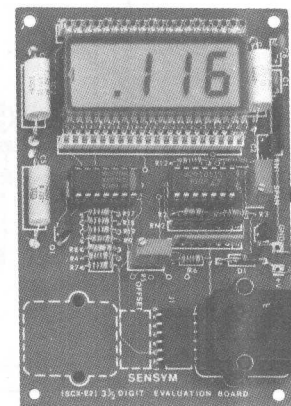
where:

$$R_T = R_{11} + R_{12}$$

As seen from the equation, the minimum gain of the amplifier ($R_T = \text{infinite}$) is two. Maximum gains of two or three hundred are achievable without excessive errors.

To determine the actual gain required, we must know the desired count needed from the A/D converter or display. As configured, the A/D converter displays one count for each 100µV applied to the input. Therefore, 200mV is required for a 1999 full-scale display.

Digital Section— The digital section is composed of three IC's; the ICL7106 (3½-digit LCD driver and A/D converter), a 3½-digit LCD display, and a quad exclusive



or gate to control the decimal points and "low bat" indicator on the display. The 7106 is a low power dual slope A/D converter containing a clock, auto zero circuit, dual slope A/D, and display drivers. The A/D reference is set to 100mV by the resistor divider R₁₄ and R₁₅. This reference sets the full-scale input voltage ($2 \times V_{REF}$); in this case $\pm 200\text{mV}$. The 3½-digit LCD display is a direct drive display with "low bat" and sign indicators.

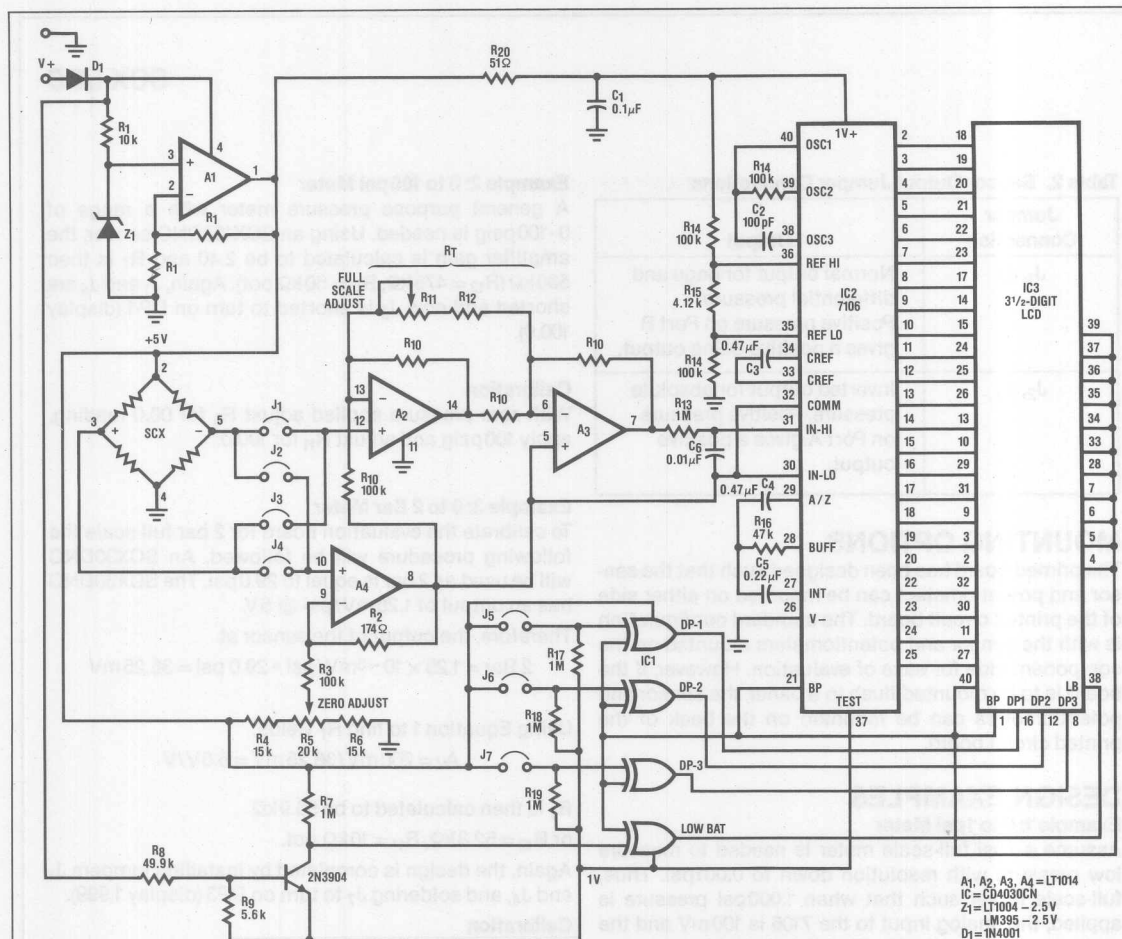
JUMPER OPTIONS

Three of the four exclusive or gates are used to control the decimal points on the display. Connecting the input high (5V) by soldering one of the shorting pads (J₅, J₆, J₇) turns on the required decimal point. Similarly, unsoldering the pad (open), turns the given decimal point off. (See Table 1). The 2N3904 transistor and the fourth exclusive or gate are used to turn on the "low bat" indicator.

Table 1. Decimal Point Jumper Connection

Jumper Connection	Decimal Point output
J ₅	DP1 (199.9)
J ₆	DP2 (19.99)
J ₇	DP3 (1.999)

The input to the amplifier is determined by soldering jumpers J₁ through J₄. To obtain positive going outputs for positive going pressures, J₁ and J₄ are shorted when using a gage or differential sensor. However, since the output of an SCXxxxAN absolute pressure sensor is negative with positive pressure, J₁ and J₄ are left open while J₂ and J₃ are shorted, thus inverting the sensor output. This inverted output is necessary, for example, when making a barometer. (See Table 2).



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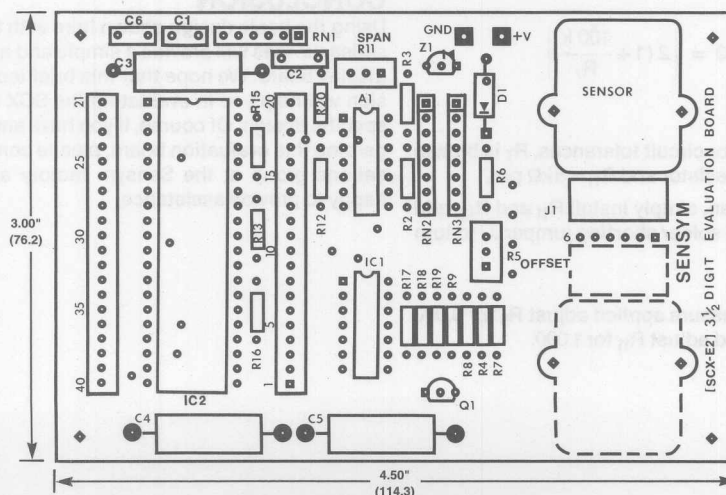


Table 2. Sensor Output Jumper Connections

Jumper Connection	Output
J ₁ , J ₄	Normal output for gage and differential pressure. Positive pressure on Port B gives a positive going output.
J ₂ , J ₃	Inverted output for absolute pressure. Positive pressure on Port A gives a positive output.

MOUNTING OPTIONS

The printed board has been designed such that the sensor and potentiometers can be mounted on either side of the printed circuit board. The standard configuration is with the sensor and potentiometers mounted on the component side for ease of evaluation. However, if the board is to be mounted flush to a panel, the sensor and potentiometers can be mounted on the back of the printed circuit board.

DESIGN EXAMPLES

Example 1: 0 to 1psi Meter

Assume a 1psi full-scale meter is needed to measure low pressure with resolution down to 0.001psi. Thus, full-scale is set such that when 1.000psi pressure is applied, the analog input to the 7106 is 100mV and the display will read 1.000. To achieve this, since an SCX01DN is ratiometric and at a supply voltage of 5V has a sensitivity of 7.5mV/psi, the amplifier is set up for a gain of 13.33:

$$A_V = 13.3 = \left[2 \left(1 + \frac{100 \text{ k}}{R_T} \right) \right]$$

Solving for R_T yields:

$R_T = 17.7 \text{ k}\Omega$. To allow for circuit tolerances, R_T is broken into: $R_{12} = 15 \text{ k}\Omega$ fixed resistor and $R_{11} = 5 \text{ k}\Omega$ pot.

To make this board then, simply install R_{11} and R_{12} , add jumpers J_1 and J_4 , and solder shorting jumper J_7 to turn on decimal point 3.

Calibration

With power and no pressure applied adjust R_5 for 0.000 reading. Apply 1psi and adjust R_{11} for 1.000.

Example 2: 0 to 100psi Meter

A general purpose pressure meter with a range of 0–100psig is needed. Using an SCX100DNC sensor, the amplifier gain is calculated to be 2.40 and R_T is then $500 \text{ k}\Omega$ ($R_{12} = 475 \text{ k}\Omega$, $R_{11} = 50 \text{ k}\Omega$ pot). Again, J_1 and J_4 are shorted and now J_5 is shorted to turn on DP-1 (display 100.0).

Calibration

With zero pressure applied adjust R_5 for 00.0 reading, apply 100psig and adjust R_{11} for 100.0.

Example 3: 0 to 2 Bar Meter

To calibrate the evaluation board for 2 bar full-scale the following procedure will be followed. An SCX30DNC will be used as 2 bar is equal to 29.0psi. The SCX30DNC has an output of 1.25mV/psi @ 5V.

Therefore, the output of the sensor at

$$2 \text{ Bar} = 1.25 \times 10^{-3} \text{ mV/psi} \times 29.0 \text{ psi} = 36.25 \text{ mV}$$

Using Equation 1 to find R_T yields:

$$A_V = 200 \text{ mV} / 36.25 \text{ mV} = 5.5 \text{ V/V}$$

R_T is then calculated to be $56.9 \text{ k}\Omega$

or $R_{12} = 52.3 \text{ k}\Omega$, $R_{11} = 10 \text{ k}\Omega$ pot.

Again, the design is completed by installing jumpers J_1 and J_4 , and soldering J_7 to turn on DP3 (display 1.999).

Calibration

With 0 psi applied adjust R_5 for 0.000 reading. Apply 1.8 bar and adjust R_{11} for a reading of 1.800 bar.

CONCLUSION

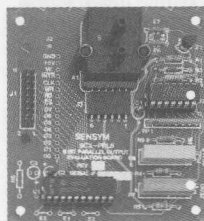
Using the basic design shown here with Sensym's SCX series devices will provide a simple and accurate digital display board. We hope that this brief technical discussion will help you in evaluating the SCX sensor in your specific design. Of course, if you have any questions regarding this evaluation board, please contact our Applications group at the Sensym factory and we will be happy to provide assistance.

FEATURES

- Parallel Data Output
- Single 5V_{DC} Supply Operation
- Pressures from 0–1 to 0–500 psi
- Bus Interface or Stand Alone Operation

INTRODUCTION

The SCX-PRL8 evaluation board is designed for applications where a parallel data interface is required with SenSym's SCX or SSX series of pressure sensors. This board can accommodate any pressure sensor application from below 1 psi up through 500 psi by simply calculating a single resistor value. The evaluation board can either be configured for a microprocessor bus interface or as a "stand alone" unit. A general discussion of the circuit and several design examples are presented to aid the designer in adjusting the evaluation board for each specific operation.



ANALOG SIGNAL CONDITIONING

Referring to evaluation board schematic in Figure I, the 1.23V reference voltage of V_R , is amplified to 3.83V for the sensor excitation voltage in order to isolate the sensor from power supply variations and noise. The $V_{IN}(-)$ and $V_{REF/2}$ nodes are also referenced to V_R so that slight variations of the reference voltage will not cause any significant output errors.

The minimum power supply voltage required is 4.85V. This limit is determined by the sensor excitation voltage of 3.83V and the output swing of the op amp which swings within one volt of the positive supply voltage.

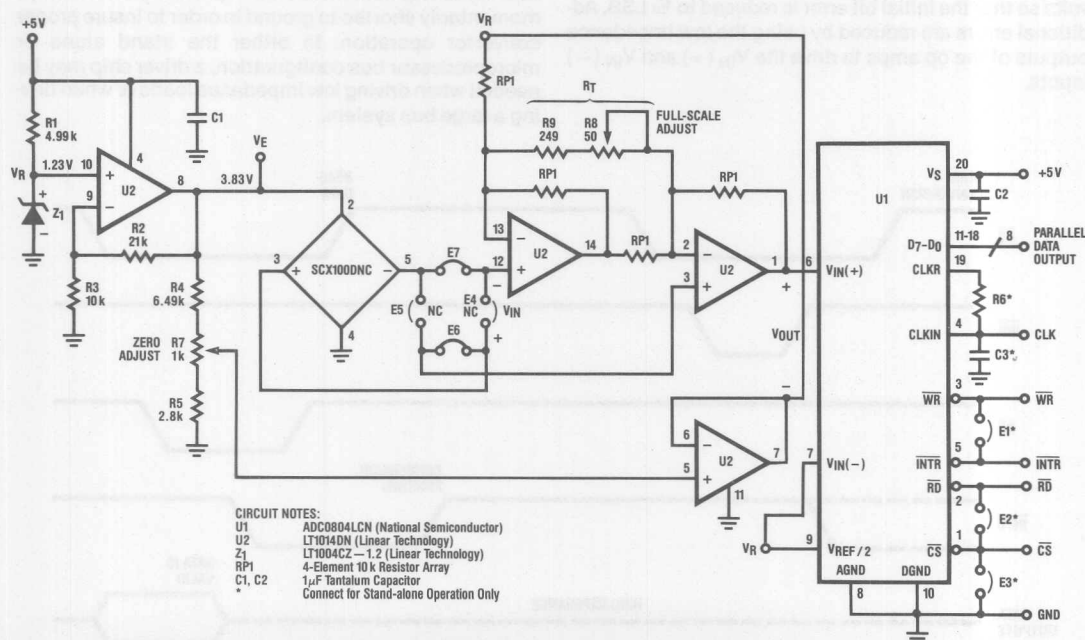


FIGURE I. A 0-to-100 psi Exercise Machine Monitor

The upper supply limit of 6.3V is limited by the maximum operating voltage of the A/D converter. Therefore, a 5V power supply with a tolerance of $\pm 3\%$ should work well with the evaluation board. Within these power supply limits, the evaluation board will typically draw 7mA.

The sensor pressure signal (V_{IN}) is amplified to provide an input signal (V_{OUT}) to the A/D converter. V_{OUT} can be expressed as:

$$V_{OUT} = 2 V_{IN} \left(\frac{R_{P1}}{R_T} + 1 \right)$$

Where: R_T consists of a fixed-value resistor (R9) and an adjustment pot (R8). The amplifier gain is adjusted by R8 such that the full-scale output is equal to twice the $V_{REF/2}$ voltage minus 1.5 LSB. This adjustment provides the best digital resolution by using the full range of the A/D converter.

The evaluation board also allows the capability of reversing the output polarity of the sensor. When using a differential or gauge sensor the board will be configured as shown in Figure I by soldering jumpers E6 and E7. If an absolute sensor is used the sensor output needs to be reversed by installing jumpers E4 and E5 (leave jumpers E6 and E7 disconnected).

At zero pressure, R7 adjusts V_{OUT} to approximately zero volts so that the initial bit error is reduced to $1/2$ LSB. Additional errors are reduced by using the low impedance outputs of the op amps to drive the $V_{IN} (+)$ and $V_{IN} (-)$ inputs.

A/D CONVERSION

The ADC0804 A/D converter, as shown in Figure I, was selected due to its low-cost, high accuracy and interface simplicity. The converter can operate with a clock frequency between 100kHz and 1.46MHz as either a microprocessor interface or in a "stand alone" configuration. Referring to Figure II, the converter operation can be summarized as follows: When $\overline{CS}$ and $\overline{WR}$ go to a logic low, the converter will start the analog to digital conversion. $\overline{INTR}$ will then go to a logic low after the conversion is finished. After $\overline{CS}$ and $\overline{RD}$ are set to a logic low, $\overline{INTR}$ will go back to a logic high and the ADC0804 will have the digital data on the tri-state output lines which allows a direct connection to the data bus. (For further information consult the ADC0804 datasheet from the National Semiconductor Corporation.)

The evaluation board can also be configured in the stand alone mode by inserting a resistor, a capacitor, and three additional jumpers (Figure I). This configuration is useful as a simple test circuit, a demonstration board, or as a debugging tool. $\overline{WR}$ is tied to $\overline{INTR}$ by jumper E1 so when $\overline{INTR}$ goes to logic low after the conversion $\overline{WR}$ also goes low thereby starting a new conversion sequence. With $\overline{CS}$ and $\overline{RD}$ tied to ground by jumpers E2 and E3, the converter outputs are being continually updated. The internal clock frequency is set by R6 and C3 such that $f(\text{clock}) = (1.1 R6 C3)^{-1}$. The only additional requirement is that on power-up $\overline{WR}$ must be momentarily shorted to ground in order to insure proper converter operation. In either the stand alone or microprocessor bus configuration, a driver chip may be needed when driving low impedance loads or when driving a large bus system.

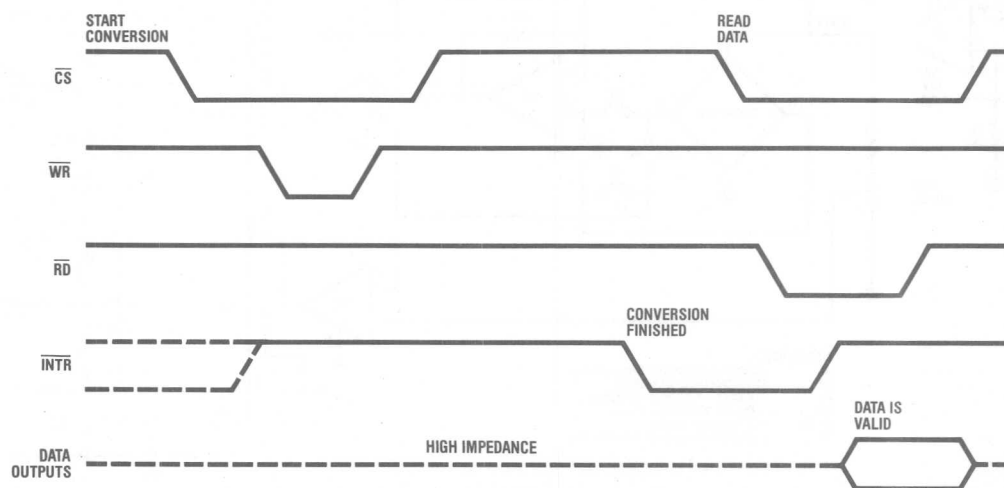


FIGURE II. ADC0804 Timing Diagram

ELECTRICAL CONNECTION

Either a wire connection or a socket connector can be used to electrically connect to the evaluation board. The evaluation board comes with a 16 contact dual row header. The male pins are 0.025" square with a 0.235" pin length on a 0.1" x 0.1" matrix. Any standard 16 contact female socket connector can be used to mate with the header. Some manufacturers of socket connectors are listed below.

16 Contact Socket Connector

Ansley (T&B)	#609-1601M
Berg (DuPont)	#66902-X16
Molex	#15-29-8162

Solder contacts have also been provided for all signals to accommodate applications where connection to a socket connector is not desired. However, using the socket connector and a cable assembly is recommended, given that the evaluation board has eight data lines and seven lines for power and control. The pinout of the socket connector and the solder connections are shown in Figure III.

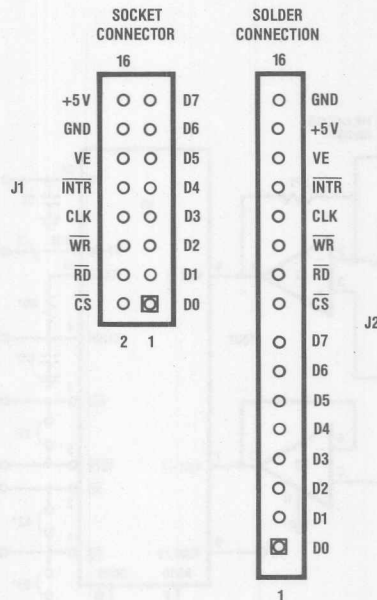


FIGURE III. SCX-PRL8 Connection Diagram

ADJUSTMENT PROCEDURE

The parallel A/D evaluation board has a simple zero and full-scale adjustment procedure.

1. With zero pressure applied, adjust the offset pot R7 so the converter output alternates between 00_H and 01_H.
2. Apply full pressure to the high pressure port (port B on SCX) and adjust R8 so that the digital output alternates between the FE_H and FF_H transition.
3. Repeat the procedure if necessary.

DESIGN EXAMPLE 1

Consider an air cylinder used in an exercise machine where the resistance is measured in PSI which is then converted and displayed as pounds. A pressure sensor is needed to measure to 0 to 100 psi pneumatic pressure and to provide a microprocessor with 8 bits of data so that the correct index number can be displayed for the user.

The digital interface can be easily achieved by using the digital evaluation board and a SCX100DNC as shown in Figure I. According to the SCX100DNC datasheet the sensor will output 100 mV at 100 psi with a 12V_{DC} excitation voltage. The output of the sensor is ratiometric to the bridge voltage, so with V_E equal to 3.83V, the SCX-100DNC will output 31.9 mV at full pressure. If the maximum digital output occurs when V_{OUT} equals 2.45V, then by using the equation for V_{OUT} and letting RP1 equal 10 kΩ, the gain resistor R_T is calculated to equal 267 Ω. By letting R9 equal 249 Ω and R8 a 50 Ω pot, the evaluation board can be adjusted for variations of the sensor span.

The zero adjustment can null out any circuit offsets of ± 180 mV by letting R7 equal a 1 kΩ pot, R5 equal a 2.8 kΩ resistor and R4 equal to a 6.49 kΩ resistor.

By following the standard adjustment procedure the evaluation board can be easily adjusted for this 0 to 100 psi application.

DESIGN EXAMPLE 2

A typical medical application for blood pressure sensing uses a 0-300 mmHg pressure and a digital interface as shown in Figure IV. For this application we will select the BP01 since this device is especially calibrated for the 0-300 mmHg medical pressure range. According to the BP01 datasheet the sensor will output 15 mV at 300 mmHg when V_E is equal to 5 V_{DC}. With V_E equal to 3.83 V the BP01 will output 11.5 mV at full pressure. The signal gain required is then 214 V/V, and so with RP1 equal to 10 k Ω R_T is calculated to equal 94.4 Ω . Let R9 equal 82.5 Ω and R8 equal a 20 Ω pot to allow for adjustment of the full-scale output. For a ± 0.35 V zero adjustment let R7 equal a 1 k Ω pot, R4 equal 3.01 k Ω , and R5 equal 1.21 k Ω .

The evaluation board can be easily calibrated by following the adjustment procedure and applying a full pressure of 300 mmHg.

DESIGN EXAMPLE 3

The oil pressure on a large truck needs to be monitored by a microprocessor. Typically, the oil pressure will range from 0 to 80 psi. For this application, the SSX100G should be used as shown in Figure V. The SSX100G has a 0 to 100 psi pressure range with a stainless steel diaphragm to protect the sensor from contaminants in the oil. From the SSX100G datasheet, the sensor will output 100 mV at 100 psi with a 12 V_{DC} power supply. With a sensor voltage (V_E) of 3.83 V and a full pressure of 80 psi, the sensor will output 25.5 mV. Therefore, if RP1 equals 10 k Ω the gain resistor R_T should equal 212 Ω with a signal gain of 96.2 V/V. By letting R9 equal 200 Ω and R8 be a 50 Ω pot, the evaluation board will be able to adjust for sensor span variations. With R7 equal to 1 k Ω pot, R4 equal to 3.0 k Ω and R5 equal to 1.21 k Ω , V_{OUT} can be adjusted ± 0.35 V to null circuit offset voltages.

By following the adjustment procedure the evaluation board can be easily adjusted for this 0 to 80 psi application.

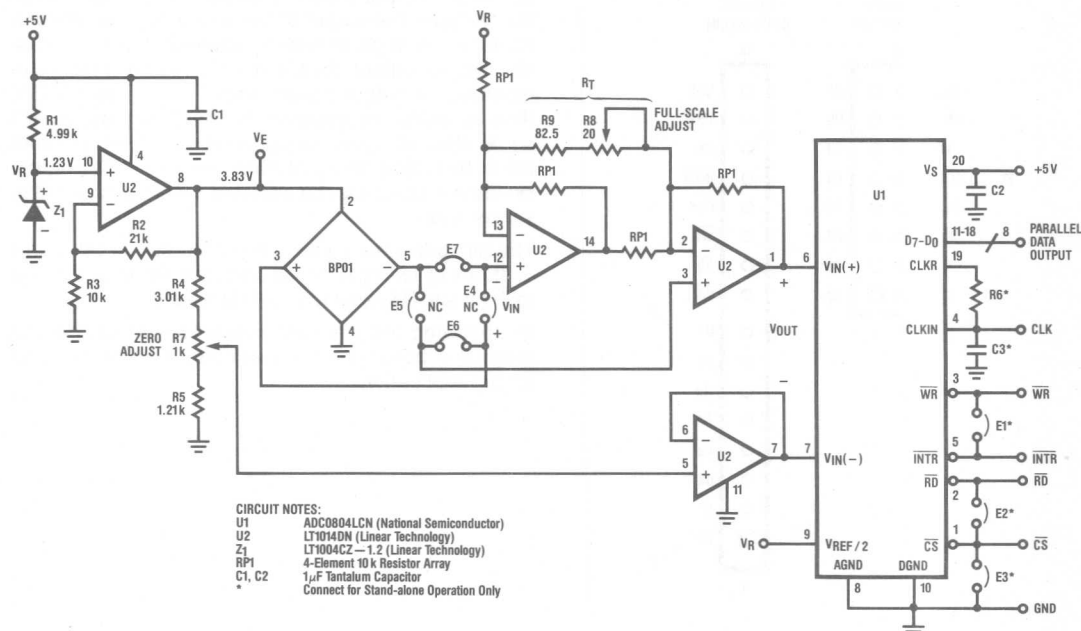


FIGURE IV. A 0-to-300 mmHg Medical Monitor

DESIGN EXAMPLE 4

An air filter monitor needs to sense a differential pressure of 0 to 10 inches of water column with a $1/10''$ H₂O resolution. This application requires the SCX01DNC pressure sensor, and the evaluation board configuration as shown in Figure VI. According to the SCX01DNC datasheet the sensor will output 18mV full-scale at 1psi with a 12V_{DC} excitation voltage. The board will be adjusted to 25.5 H₂O and will provide a $1/10''$ H₂O resolution. With a sensor supply of 3.83 and a pressure of 25.5'' H₂O, the full-scale output is 5.3mV. With V_{OUT} equal to 2.456V, the gain required is 464V/V. With R_{P1} equal to 10k Ω , the gain resistor R_T is calculated to equal 43.3 Ω . Let R₉ equal 33.2 Ω and R₈ a 20 Ω pot to allow the evaluation board to adjust for sensor span variations.

To allow a ± 850 mV null adjustment, let R₄ equal to 10k Ω resistor, R₅ a 2k Ω resistor and R₇ a 10k Ω pot.

By following the standard adjustment procedure, the evaluation board can be easily adjusted for this 0 to 25.5'' H₂O application. 10'' H₂O column of pressure will have an output of 64_H with one LSB representing 0.10'' H₂O column.

IN SUMMARY

The SCX-PRL8 evaluation board allows a simple interface between a pressure sensor and a microprocessor bus, we hope this technical discussion will aid you in the evaluation of Sensym's pressure sensors. To this end, Figure VII is provided to aid you with your design. If further technical assistance is needed please contact Sensym's Application Department.

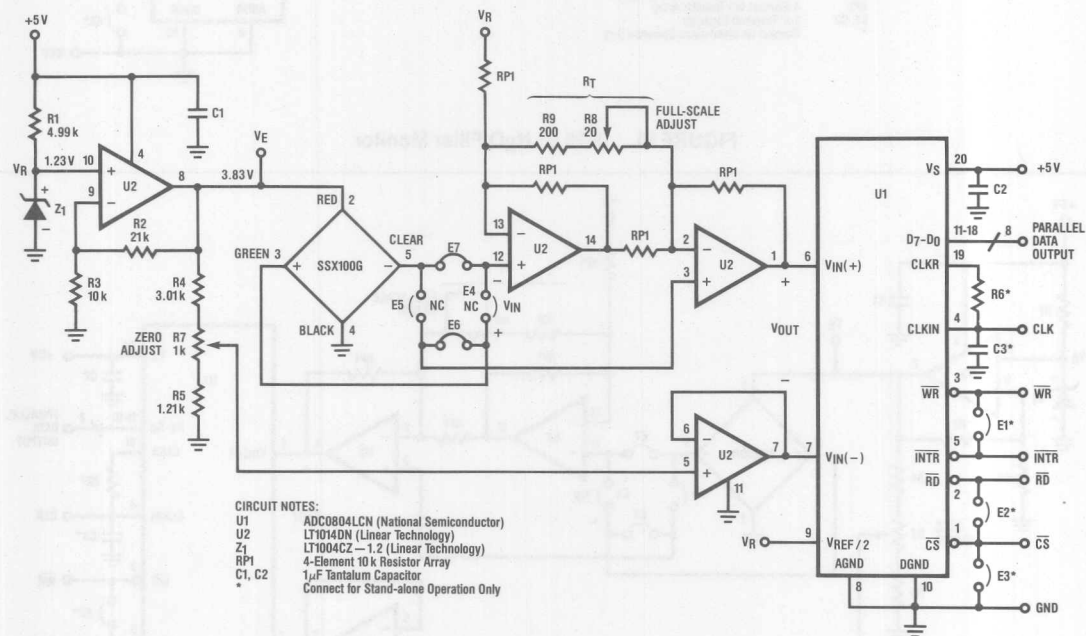


FIGURE V. A 0-to-80 psi Oil Pressure Monitor

SCX-PRL8

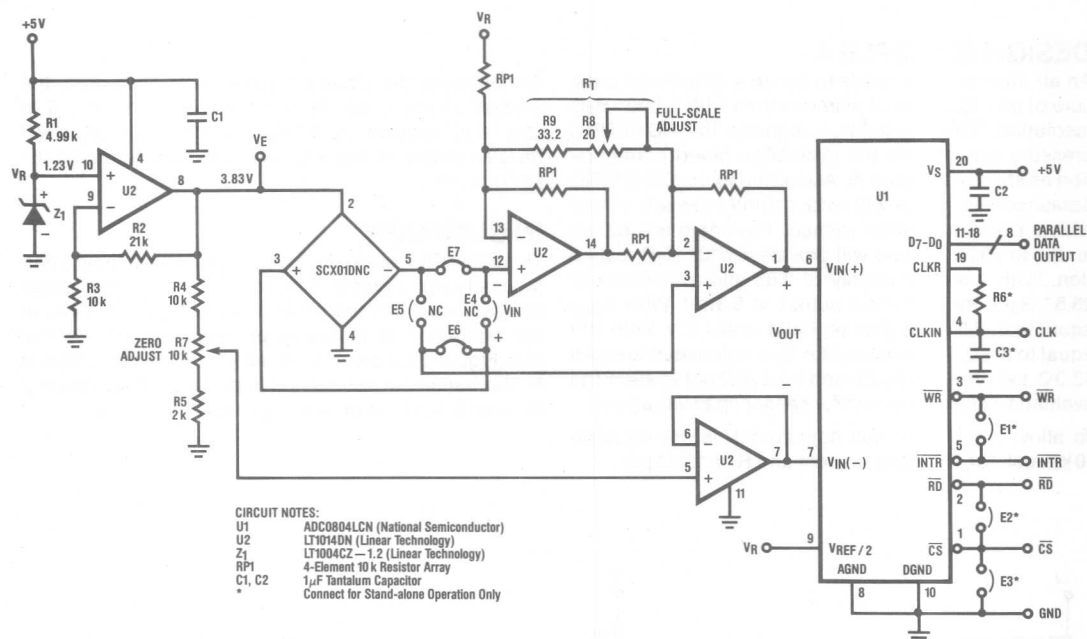


FIGURE VI. 0-25.5" H₂O Filter Monitor

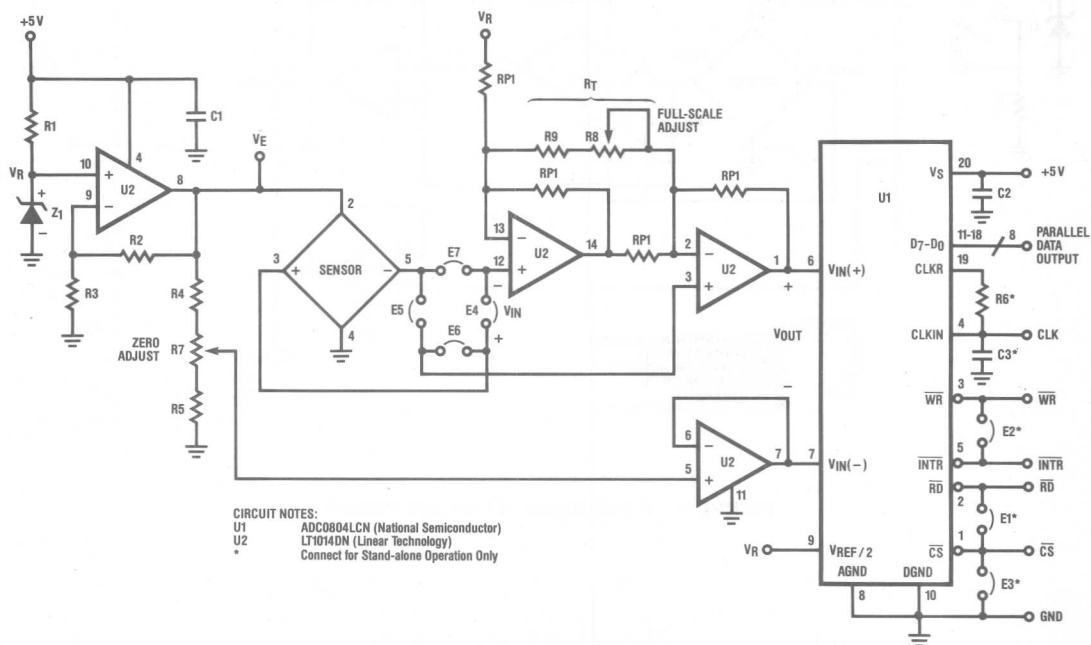
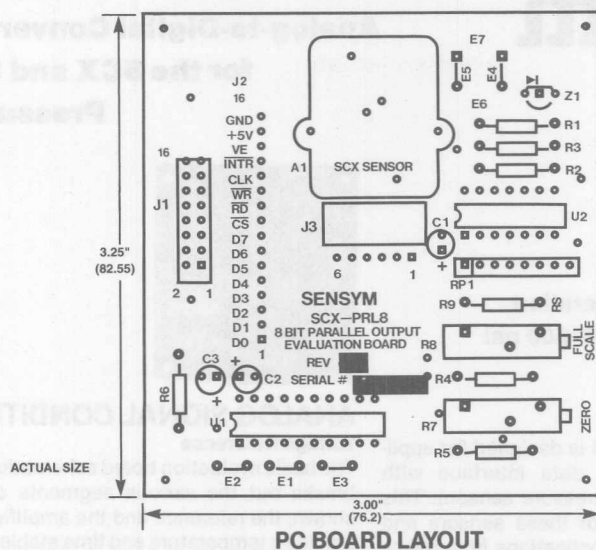


FIGURE VII. Circuit for Your Design

PHYSICAL DIMENSIONS

SCX-PRL8



ORDERING INFORMATION

To order evaluation boards, complete the form shown on the previous page. Evaluation boards are available for all standard SCX Series devices shown below. For other pressure ranges, please contact the Sensym factory. Each evaluation board includes the PC board with all components, including the SCX "C" series sensor pre-assembled and ready to use.

Sensym also has available evaluation boards that provide a voltage output, 8-bit serial output, and a 3½-digit LCD display. Please contact the Applications Department at Sensym for further details.

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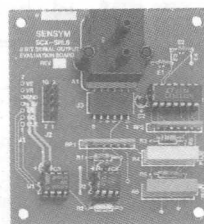
STANDARD PRESSURE RANGES

Part Number	Operating Pressure	Proof Pressure*
SCX01DNC	0 - 1 psid	20 psid
SCX05DNC	0 - 5 psid	20 psid
SCX15ANC	0 - 15 psia	30 psia
SCX15DNC	0 - 15 psid	30 psid
SCX30ANC	0 - 30 psia	60 psia
SCX30DNC	0 - 30 psid	60 psid
SCX100ANC	0 - 100 psia	150 psia
SCX100DNC	0 - 100 psid	150 psid
SCX150ANC	0 - 150 psia	150 psia
SCX150DNC	0 - 150 psid	150 psid

* Maximum pressure above which causes permanent sensor failure.

FEATURES

- Serial Data Output
- Single 5V_{DC} Supply Operation
- Pressures from 0–1 to 0–500 psi
- Instant Prototyping



INTRODUCTION

The SCX-SRL8 evaluation board is designed for applications that require a serial data interface with Sensym's SCX or SSX Series pressure sensors. This board can accommodate any of these sensors and allows instant prototyping for applications from below 1psi up through 100psi by simply calculating a single resistor value. A general discussion of the circuit and several design examples are presented to aid the designer in adjusting the evaluation board for each specific application.

ANALOG SIGNAL CONDITIONING

Voltage Reference

The basic evaluation board schematic shown in Figure 1 breaks out the various segments of the circuit. As shown, the reference and the amplifier of the LM10(U2) provide a temperature and time stable voltage reference for the sensor and A/D converter. The 200 mV reference provided by the LM10 is amplified to V_R setting the reference (V_{REF}) on the A/D converter to 1.41V. Therefore, when V_{OUT} equals 1.40V the A/D converter will output the maximum digital code. The amplifier on the LM10

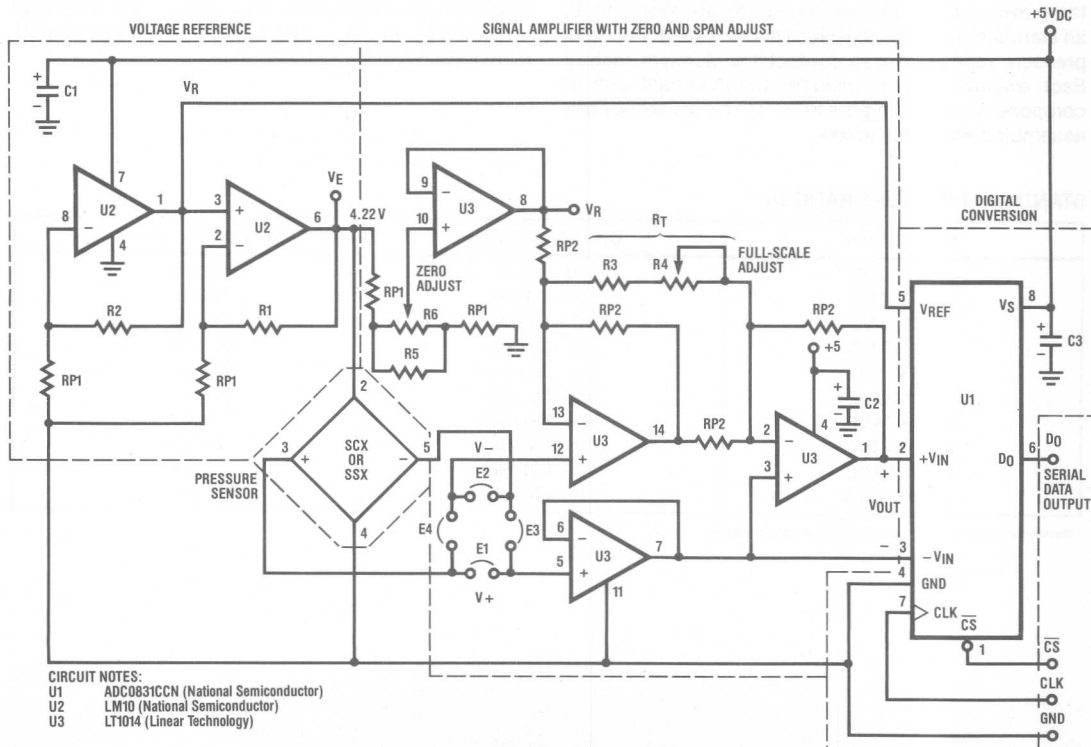


FIGURE 1. SCX-SRL8 Basic Circuit Diagram

gains V_R to 4.2V for the sensor excitation voltage (V_E). The A/D converter reference, the sensor excitation voltage and the zero reference adjustment are then ratio-metric to the LM10 reference. Therefore, slight changes in the reference voltage will not cause any significant output errors.

The power supply voltage range of the evaluation board is between 4.80V and 6.3V. The minimum supply voltage is set by the sensor excitation voltage of 4.2V and the fact that the op amp output can only swing to within 400mV of the positive supply. The maximum voltage supply is limited by the A/D converter to 6.3V. Therefore, a 5V power supply with a $\pm 3\%$ tolerance works well with the evaluation board and it will typically draw 5mA of supply current.

Amplifier

The instrumentation amplifier consisting of U3 provides gain to the sensor outputs, V_+ and V_- . The full range of the converter is used by adjusting R4 at full pressure, so that V_{OUT} is equal to the voltage at V_{REF} minus 1.5LSB. V_{OUT} can be expressed as follows in Equation 1:

$$V_{OUT} = [(V_+) - (V_-)] [2(RP2)/R_T + 3/2] \quad (1)$$

This three op amp instrumentation configuration allows V_{OUT} to be at the same common-mode voltage as the sensor outputs and takes advantage of the excellent common-mode rejection of the ADC0831. Source impedance errors are minimized by connecting the converter inputs to the low impedance op amp outputs.

DIGITAL INTERFACE

The A/D converter circuit requires a clock, a chip select ($\overline{CS}$), a data output, $+5V_{DC}$ power and a common ground line to complete the digital interface shown in Figure I. The timing diagram for the ADC0831 shown in Figure II, can be summarized as follows:

- (1) When $\overline{CS}$ goes low, the A/D converter will start a new conversion on the next rising edge of the clock after the 250 ns set-up time.
- (2) On the next falling edge of the clock, the data output, D_O , will have the zero start bit.

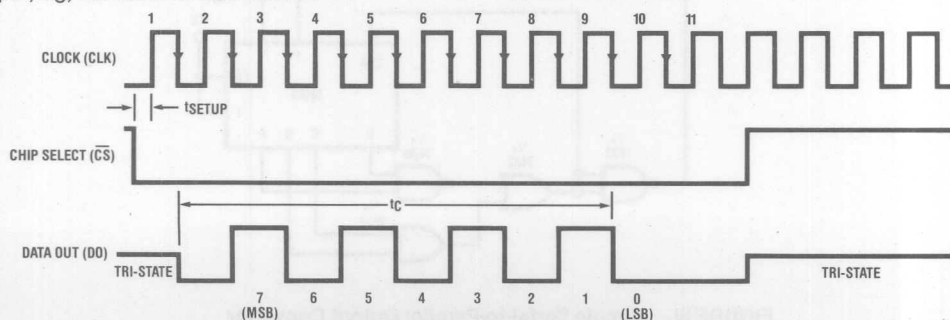


FIGURE II. ADC0831 Timing Diagram

- (3) On the next eight consecutive falling edges of the clock, the data output line will have the converted digital output. The ADC0831 has tri-state logic outputs so that more than one device can be placed on the same data line where each I/O device is addressed through its chip select line. (See the ADC0831 datasheet from National Semiconductor Corporation for further information.)

The data output line can be read using an oscilloscope, a microprocessor or a simple serial-to-parallel converter as shown in Figure III. A chip select line is used to start the conversion by setting the control registers. The serial data is loaded into a shift register and after eight bits have been loaded, the parallel output buffers are enabled and the digital output can be read.

JUMPER CONNECTIONS

For gauge and differential pressure measurements, solder connectors E1 and E2 are closed. This connection provides a digital output that will increase as the pressure increases on Port B of the SCX sensor. However, if an absolute pressure sensor is used, the digital output will decrease with an increase of pressure on port A with the same connection. The sensor output polarity must then be reversed by installing jumpers E3 and E4. This connection enables the evaluation board to provide an increasing digital output for an increasing pressure on port A of an SCX absolute sensor.

OFFSET ADJUST

The voltage divider with the pot R6 allows enough adjustment to null all of the given sensor common-mode and offset voltages at zero pressure. If less adjustment range is desired, resistor R5 can be connected in parallel with R6 in order to improve calibration ease.

FULL-SCALE ADJUST

The combination of R3 and R4 allows enough adjustment to calibrate the evaluation board for variations of the sensor span. R4 should be adjusted so that the maximum digital output is displayed when full pressure is applied to the sensor.

ELECTRICAL CONNECTION

The electrical connections to the board are made by either a single row header or by solder connections. The header consists of five 0.025" square male pins on 0.1" centers. Any standard, single row female socket connector can be used to mate with the header. However, a single row female connector may not be as readily available as a dual row connector. Here are some manufacturers of a dual row, 10 contact, female connector that may be easier to obtain.

Ansley 609-1001M
Berg 66902-X10
Molex 15-19-8102

A manufacturer of single row socket connectors is:

Samtec #IDS-36-G.

A simple alternative method to electrically connect to the evaluation board, is to use the five solder connections. The five signals, which include +5V, GND, D₀, CS, and CLK, are all that is needed to operate the board.

A diagram of the signal pin out for the socket connector and the solder connections is shown in Figure IV.

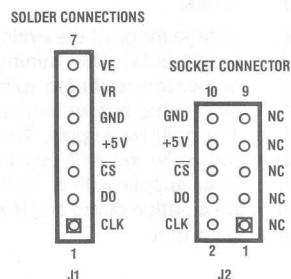


FIGURE IV. Evaluation Board Pinout Diagrams

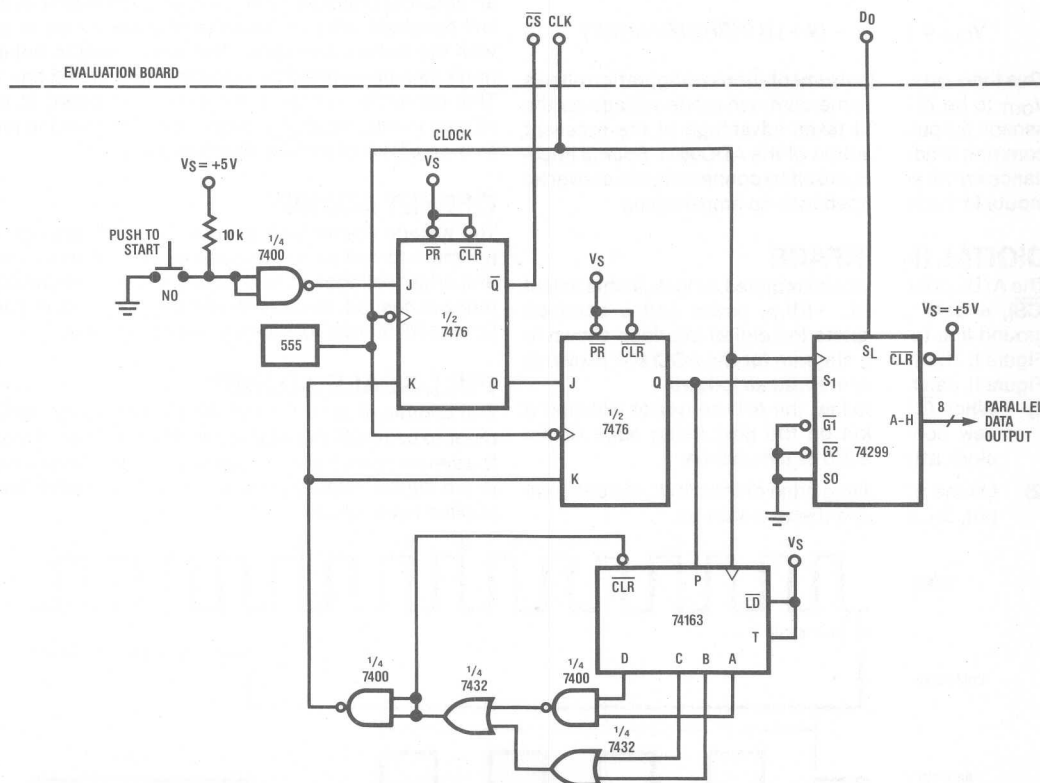


FIGURE III. Simple Serial-to-Parallel Output Converter

DESIGN EXAMPLE 1

Filter Condition Monitor

Consider the need to monitor the differential pressure across an industrial air filter. It is a simple task for a microprocessor to keep track of the filter with an output of 00_H representing an missing filter, 37_H (6 in. H₂O) representing a clean filter, and FF_H (27.7 in. H₂O) representing a blocked or clogged filter. Codes in between can represent degrees of blockage and signal cautionary indicators.

This air filter monitor can be made by using a 0-to-1psi sensor, the SCX01DNC as shown in Figure V. According to the SCX01DNC datasheet, at 27.68 in. H₂O, the sensor will output 18mV with a 12V supply. However, since the sensor is ratiometric to the power supply, the full scale output will be 6.3mV with a 4.2V supply. From Equation 1, if V_{OUT} must equal 1.40V in order to obtain the maximum digital output (FF_H) and V_{IN} equals 6.3mV, then the voltage gain required is 221V/V.

Once the signal gain is known, the gain resistor can be calculated from Equation 1. If RP2 equals 10k Ω , then R_T equals 91 Ω . By letting R_T consist of R3 equal to an 80.6 Ω 1% metal film resistor and R4 equal to a 20 Ω multturn cermet pot, the circuit can be adjusted for devices with slightly different full scale outputs.

To allow ± 700 mV of zero adjustment, R6 is a 10k Ω multturn cermet pot. To improve resolution, an R5 of 30.1k Ω can be connected in parallel to provide a zero adjustment range of ± 575 mV.

Adjustment Procedure

- With zero differential pressure applied, adjust R6 until the digital output alternates between 00_H and 01_H.
- Apply 27.68 inch H₂O differentially across the pressure ports with port B as the high pressure port. Adjust R4 such that the digital output alternates between FE_H and FF_H translation.
- Repeat (A) and (B) as required.

DESIGN EXAMPLE 2

Pneumatic Systems Monitor

A microprocessor must monitor a 3–15psig industrial process. A digital output of FF_H represents 15psig, while an output of 00_H represents 3psig. The evaluation board can be used for this application by simply calculating a new gain resistor and using an SCX315DNC as shown in Figure VI. From the SCX315DNC data sheet, the sensor will typically output 72mV at 15psig with a 12V power supply. The output of the SCX315DNC is also ratiometric with the supply voltage. Therefore, with a 4.2V supply the full scale output is 25.3mV. Using Equation 1, if V_{OUT} must equal 1.40V to obtain the maximum digital code, then the signal gain required is 55.2V/V.

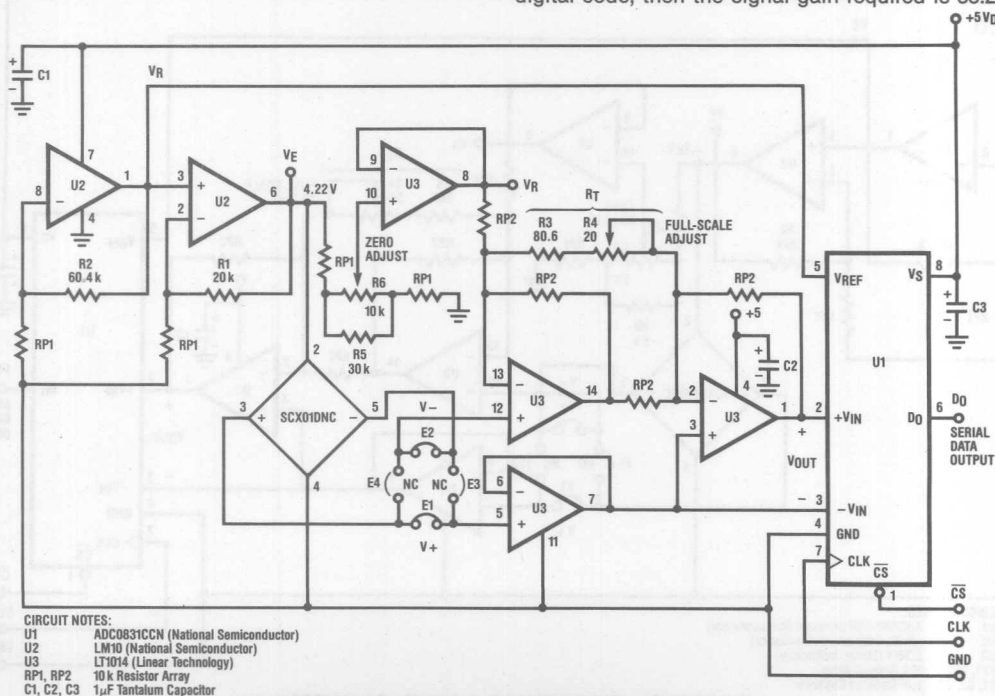


FIGURE V. A 0-to-1psi Air Filter Monitor

For $RP2$ equal to $10\text{ k}\Omega$, R_T is calculated to equal 376Ω . Let R_T consist of $R3$ equal to a 348Ω 1% metal film resistor and $R4$ equal to a 50Ω cermet pot to allow for adjustment of span variations between different devices.

By letting $R6$ be a $5\text{ k}\Omega$ pot, this zero adjustment will provide $\pm 420\text{ mV}$ to compensate for the sensor offset voltage. The full adjustment range of $R6$ is not needed, therefore $R5$, a $5\text{ k}\Omega$ resistor, is connected in parallel to $R6$ providing $\pm 235\text{ mV}$ of adjustment.

Adjustment Procedure

- With 3psig pressure, adjust $R6$ such that the digital output alternates between 00_H and 01_H .
- Apply 15psig to port B on the SCX315DNC, and adjust $R4$ so that the digital output alternates between FE_H and FF_H .
- Repeat (A), and (B) if necessary.

DESIGN EXAMPLE 3

Waste Water Line Pressure

A microprocessor monitors the line pressure in a waste water system. The normal line pressure is approximately 25psig, however, if an obstruction occurs in the pipeline, it is desired to have the microprocessor turn off a sump pump at 50psig of back pressure. This will prevent the sump from overflowing as well as prevent the pump from overheating.

This application requires a circuit that uses the SSX100G with its stainless steel diaphragm to isolate the pressure sensing element from the waste water as shown in Figure VII. The line pressure monitor will read to zero pressure so as to indicate proper line operation and possible leaks. The SSX100G will output 100 mV at 100 psig with a 12 V supply. The SSX100G is ratiometric with the supply voltage so with a 4.2 V supply and 50 psig , the sensor will output 17.6 mV . If the A/D converter requires a 1.40 V signal in order to obtain the maximum digital output, then by using Equation 1, the required gain is 80 V/V . With $RP2$ equal to $10\text{ k}\Omega$, R_T is calculated to equal 256Ω . By letting $R3$ equal a 237Ω 1% metal film resistor and $R4$ equal a 50Ω cermet pot, adjustments can be made for sensor span variations.

With $R6$ a $5\text{ k}\Omega$ pot, the zero adjustment allows $\pm 420\text{ mV}$ adjustment for the sensor offset voltage. The entire adjustment range of the pot is not needed. So, $R5$ is connected as a $5\text{ k}\Omega$ resistor and this provides $\pm 235\text{ mV}$ of zero adjustment.

At 50 psig full pressure, the A/D converter will be adjusted to output FF_H . If the digital output is 00_H at zero pressure, then the normal line pressure of 25 psig will have a digital output of 80_H .

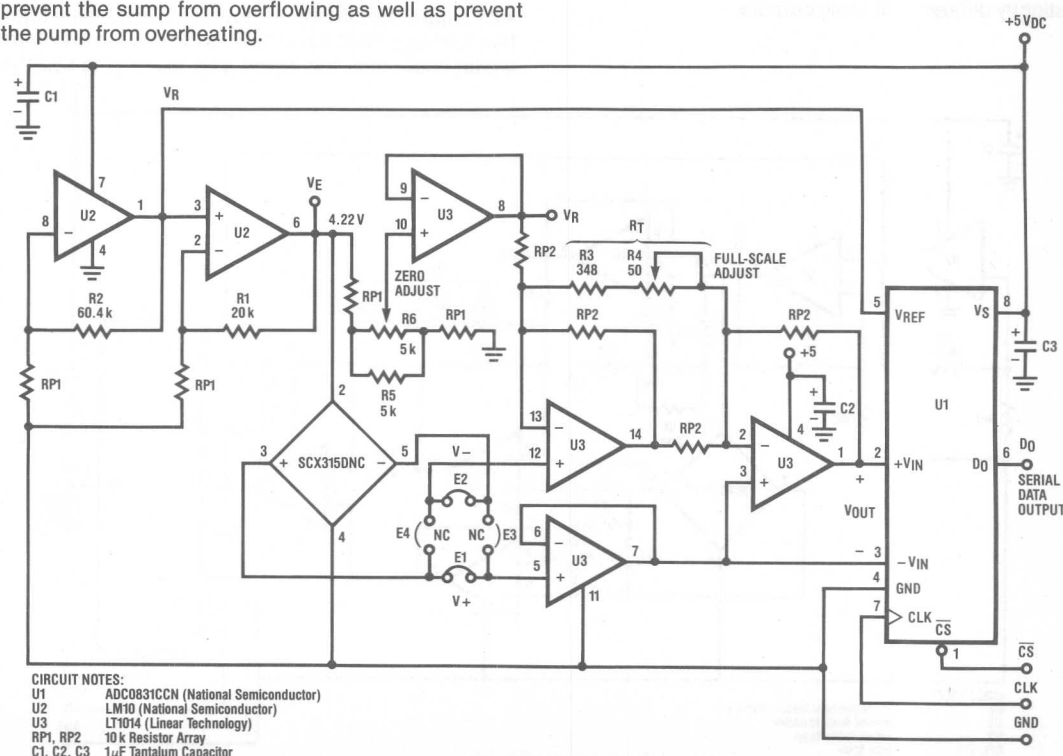


FIGURE VI. A 3-to-15 psi Pneumatic Control Monitor

Adjustment Procedure

- (A) Apply zero pressure to the sensor. Adjust R6 such that the digital output alternates between the 00_H and 01_H transition.
- (B) Apply 50 psig to the SSX100G and adjust R4 to produce a digital output that alternates between FE_H and FF_H.
- (C) Repeat (A) and (B) as necessary.

IN SUMMARY

The SCX-SRL8 evaluation board allows a simple way to breadboard the analog-to-digital interface between a pressure sensor and a computer system. We hope this brief technical discussion and the design examples will aid you in the evaluation of Sensym's SCX and SSX pressure sensors. If further technical assistance is required, please contact the Applications Department at Sensym.

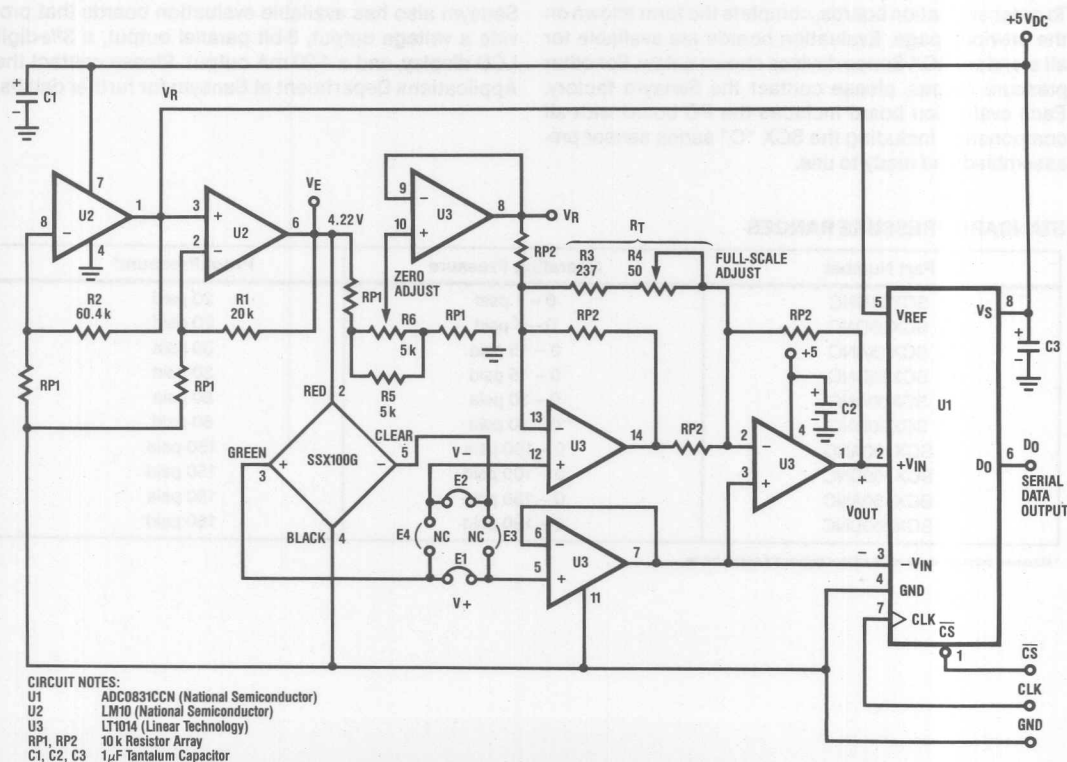
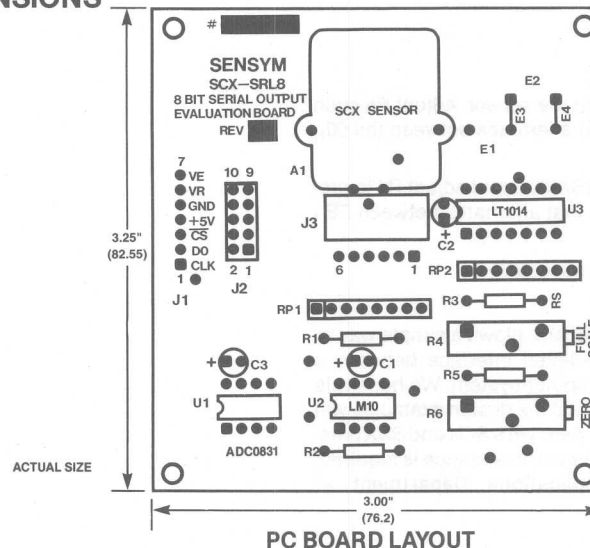


FIGURE VII. A 0-50 psi Line Pressure Monitor

PHYSICAL DIMENSIONS

SCX-SRL8



ORDERING INFORMATION

To order evaluation boards, complete the form shown on the previous page. Evaluation boards are available for all standard SCX Series devices shown below. For other pressure ranges, please contact the Sensym factory. Each evaluation board includes the PC board with all components, including the SCX "C" series sensor pre-assembled and ready to use.

Sensym also has available evaluation boards that provide a voltage output, 8-bit parallel output, a 3½-digit LCD display, and a 4-20 mA output. Please contact the Applications Department at Sensym for further details.

STANDARD PRESSURE RANGES

Part Number	Operating Pressure	Proof Pressure*
SCX01DNC	0 - 1 psid	20 psid
SCX05DNC	0 - 5 psid	20 psid
SCX15ANC	0 - 15 psia	30 psia
SCX15DNC	0 - 15 psid	30 psid
SCX30ANC	0 - 30 psia	60 psia
SCX30DNC	0 - 30 psid	60 psid
SCX100ANC	0 - 100 psia	150 psia
SCX100DNC	0 - 100 psid	150 psid
SCX150ANC	0 - 150 psia	150 psia
SCX150DNC	0 - 150 psid	150 psid

* Maximum pressure above which causes permanent sensor failure.

SenSym

SOLID STATE SENSORS

SMRT Evaluation Board (SMRT-EB)

INTRODUCTION

The SMRT-EB is a complete interface module designed to work with a SenSym SMRT pressure transducer. The SMRT series pressure transducer is digitally compensated, self contained, digital output pressure transducer. The SMRT-EB is an assembled printed circuit board containing all the hardware necessary to operate the SMRT series transducer in a local (stand alone mode) as well as a remote (PC compatible) control mode.

GENERAL DISCUSSION

HARDWARE — The following discussion provides a description of the SMRT-EB board and the associated hardware provided.

Each assembled SMRT-EB contains:

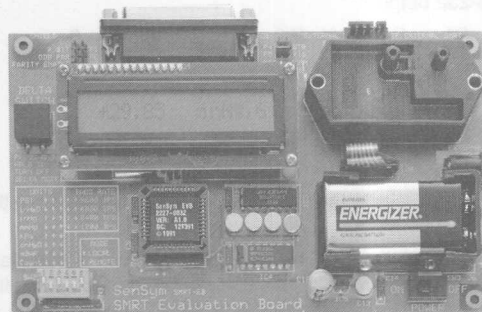
- 1—16 character single line LCD display (5 x 8 dot character matrix) capable of displaying upper and lower case alpha and numeric characters
- 1—6 position dip switch which sets the display units, baud rate, and local/remote mode
 - Switches 1, 2, and 3 select display units
 - Switches 4 and 5 set baud rate
 - Switch 6 sets local/remote mode
- 1 — Delta Mode enable switch
- 5 — RS-232 mode select jumpers
- 1 — RS-232 serial output port
- 1 — Battery Holder
- 1 — External power jack

Each SMRT-EB is shipped with the following accessories.

- 1 — 9V AC Adapter
- 1 — 5¼" Floppy Disk containing evaluation software for use with a PC
- 2 — Cables to interface the SMRT-EB to a PC
- 1 — SMRT Transducer
- 1 — 9 Volt Battery

POWER — The SMRT-EB board input voltage range is 7 V_{DC} to 15 V_{DC}. A standard 9V alkaline battery will provide greater than 20 hours of continuous operation, a "Low Battery" error condition will be displayed when the battery voltage is 5.5 V or less.

The SMRT-EB board also contains a 2 mm external power jack which disconnects the on board battery and allows the EB board to be powered from an external 9V AC adapter.



SMRT MOUNTING OPTIONS — The SMRT-EB board has provisions to mount the SMRT device on the board (6 position flex cable connector) or external to the board through a 6-pin 0.100" spaced single row polarized connector. The two connectors are connected in parallel so only one SMRT (local or remote) can be connected at one time. The SMRT evaluation board is shipped ready for on board operation. However for remote SMRT transducer operation a Molex 6373 series male header is mounted on the board, a 6-pin 2695 series female connector is supplied by the user. The external connector can also be used to monitor the interface signals to the on board SMRT pressure transducer.

Molex Female Matting Connector part no.

Without locking Ramp or Ribs	22-01-2061
With locking Ramp	22-01-2067
With Locking Ramp and Polarizing Ribs	22-01-3067

PRESSURE DISPLAY UNITS AVAILABLE

DIP switches 1, 2, and 3 of SW-2 select one of the following display units

Switch	1	2	3	Switch	1	2	3
PSI	on	on	on	mBar	on	off	off
inH ₂ O	off	on	off	cmH ₂ O	off	on	off
inHg	on	off	on	mmHg	off	off	on
KPa	on	on	off	Count	off	off	off

Note: Count outputs the binary compensated SMRT transducer output (10,000 counts full-scale).

SMRT Evaluation Board

JUMPER BLOCKS (RS-232 OPTIONS)

The SMRT-EB has 5 jumper blocks which select the Parity, Data Bits, and RTS or DTR handshake function for the RS-232 output.

P1	Data Bits - 7/8	Open = 8
P2	Parity - Odd/Even	Open = Even
P3	Parity - Enable/Disable	Open = Disable
P4	Data Terminal Ready	Short = DTR or
P5	Request to Send	Short = RTS

P4 or P5 Selects the handshake (data flow control) to the host.

DIAGNOSTIC MODE — The SMRT-EB has a self diagnostic sequence which can be selected by depressing the delta switch as the power is applied. The sequence of diagnostic displays are:

1. Diagnostic Mode
2. SMRTxxxxx (Model Display)
3. xxx to xxx PSID (Pressure Range Display)
xxx to xxx PSIG
xxx to xxx PSIA
4. Pressure Port Assignment
P1 +, P2 unused (Absolute Devices)
P1 Ref, P2 + (Gage and positive differentials)
P1 Ref, P2 + / - (Positive and Negative Diff.)
5. Serial No. xxxxxx (SMRT device Serial No.)
6. Remote - xxxx Baud (Operating mode & Baud rate)
Local - xxxx Baud
7. Even Parity (Parity)
Odd Parity
No Parity
8. x Data Bits (Data Bit Length)

The displays are sequenced upon each depression of the Mode switch, if the delta mode switch is not pressed for 15 seconds the next display will be selected. After the last display of the sequence is complete the evaluation board will enter the local or remote operating mode as determined by the position 6 of SW-2.

Note: Serial interface operation during diagnostic mode.

- | | | |
|-------|---|--------------------|
| Pin 2 | - | TxD in, Ignored |
| 3 | - | RxD out, Inactive |
| 4 | - | RTS in, Ignored |
| 5 | - | CTS out, Not ready |
| 6 | - | DSR out, Not ready |
| 20 | - | DTR in, Ignored |

LOCAL OPERATING MODE

In the local mode the board is controlled by DIP switches, this mode does not support any RS-232 commands. The display data is, however, sent out the RS-232 port at each display update. In the Local mode the SMRT-EB board can be operated as a stand alone, battery operated, pressure calibration device to check other sensors or any pneumatic system.

1. LOCAL MEASURING MODE — When measuring pressures in the local mode the display format will be as follows:

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 (digit)
D S P P P P P P U U U U U , M (pressure display)

D = Delta mode indicator

S = sign

P = Pressure reading (including decimal point)

U = units (DIP switch selectable)

M = Measurement (A = absolute, G = gage)

LOCAL MODE TIMING:

1. Sample rate 80 ms.
2. Display update rate 480 ms.

2. LOCAL DELTA MODE — Depressing the delta mode switch puts the evaluation board in a delta or difference reading mode. The initial reading (pressure at the time the switch is pressed) is stored and the display is set to zero, each subsequent reading is compared to the initial reading and the difference is displayed. Momentarily depressing the Delta switch again will acquire a new Delta reference reading. The EB board will stay in this mode until the DELTA switch is held down for a time greater than 1 second or the power is turned off.

Note: Serial interface operation during local mode:

- | | | |
|-------|---|--------------------|
| Pin 2 | - | TxD in, Ignored |
| 3 | - | RxD out, Active |
| 4 | - | RTS in, Ignored |
| 5 | - | CTS out, Not ready |
| 6 | - | DSR out, Not ready |
| 20 | - | DTR in, Ignored |

The output format for the serial interface is:

<pressure display><cr><lf>

Where the pressure display is a string of 16 ASCII characters.

SMRT Evaluation Board

REMOTE MODE

The remote mode is selected by DIP switch position 6 SW2. In the remote mode the Delta switch SW1 is inactive and the serial interface (RS-232) is active.

Remote Mode Commands:

- 1 - Display Pressure in PSI
- 2 - Display Pressure in inches of water
- 3 - Display Pressure in inches of mercury
- 4 - Display Pressure in millimeters of mercury
- 5 - Display Pressure in kilopascal
- 6 - Display Pressure in centimeters of water
- 7 - Display Pressure in millibar
- 8 - Display Pressure in Count
- A - port assignments
- D - set Delta Mode
- M - SMRT model number
- N - set normal mode (non delta)
- R - SMRT pressure range
- S - SMRT serial number

The serial output rate is dependent upon the command rate while the serial output format is as follows:

< command (echoed) > < space > < response > < cr > < lf >

where: < command > is the received ASCII command

< space > is a space character

< response > is the response ASCII string (16 characters in length)

diagnostic modes 2-5 displays

error condition displays

pressure reading as described in the local measuring mode display

< cr > carriage return character

< lf > line feed character

All control characters (OOH through 1FH) are echoed without further action.

< command (echoed) >

SMRT EVALUATION SOFTWARE

The SMRT evaluation software provided with the SMRT-EB can be used to control the EB using a PC and the RS-232 cable provided.

To use the evaluation software, the evaluation board must have the jumpers and DIP switches configured as follows = (4800 Baud, 8 Data Bits, No Parity, and RTS handshake):

DIP Switch	1	2	3	4	5	6	
	X	X	X	off	on	X	(X= Don't care)
Jumpers	P1	no jumper					
	P2	no jumper					
	P3	no jumper					
	P4	no jumper					
	P5	jumper installed (RTS handshake)					

The command line needs a parameter to specify the proper COM port.

Command Line SMRTEVAL <Serial Port Number>

<Serial Port Number> = 1, Selects COM1

<Serial Port Number> = 2, Selects COM2

Example:

1 - Insert EB floppy

2 - Type SMRTEVAL 1

(SMRTEVAL 1 - Runs the evaluation utility on COM1)

Ctrl X = Exit

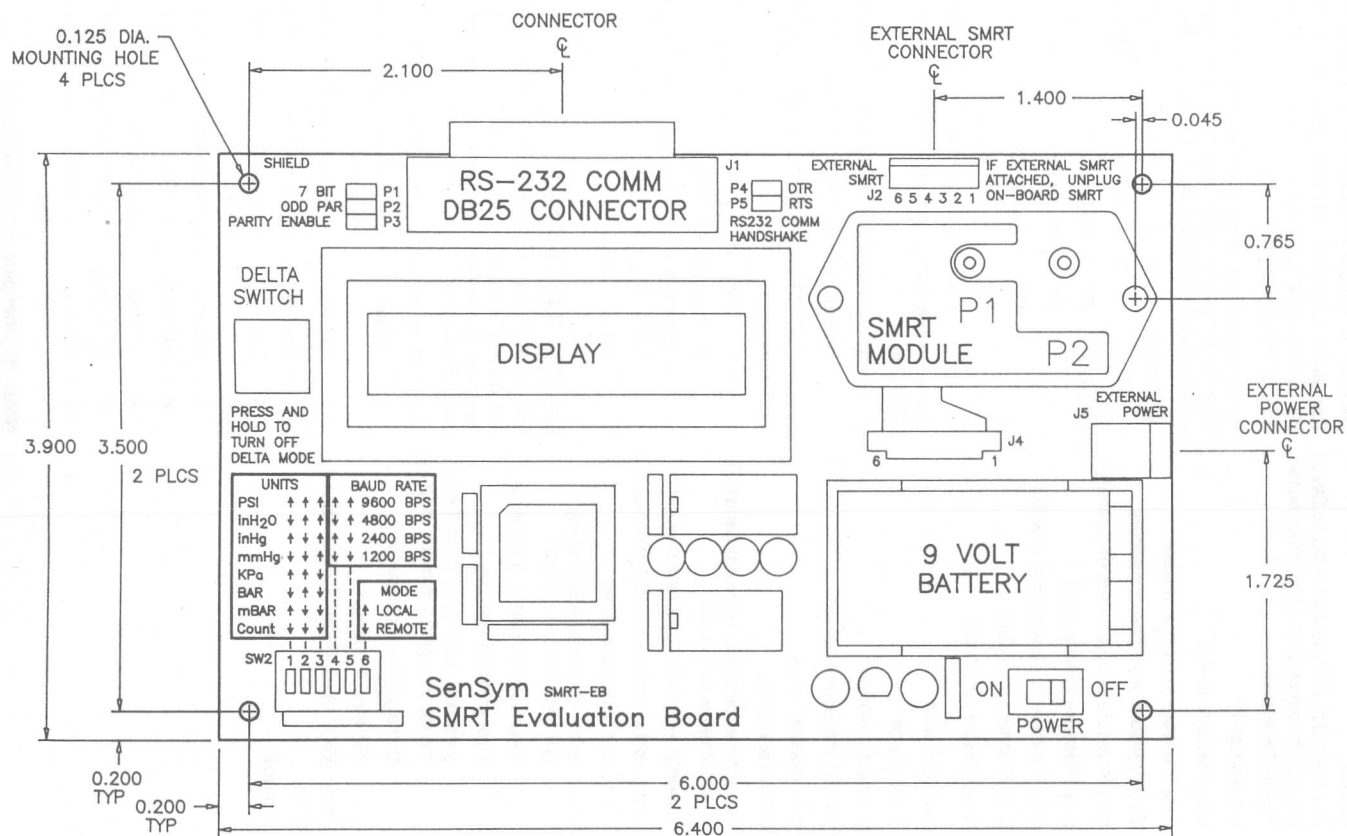
RS-232 INTERFACE

The serial interface is an RS-232 interface wired for DCE use (PC compatible). The baud rate is DIP switch selectable from 1200 to 9600 baud and the data format (parity and data bit length) is jumper selectable.

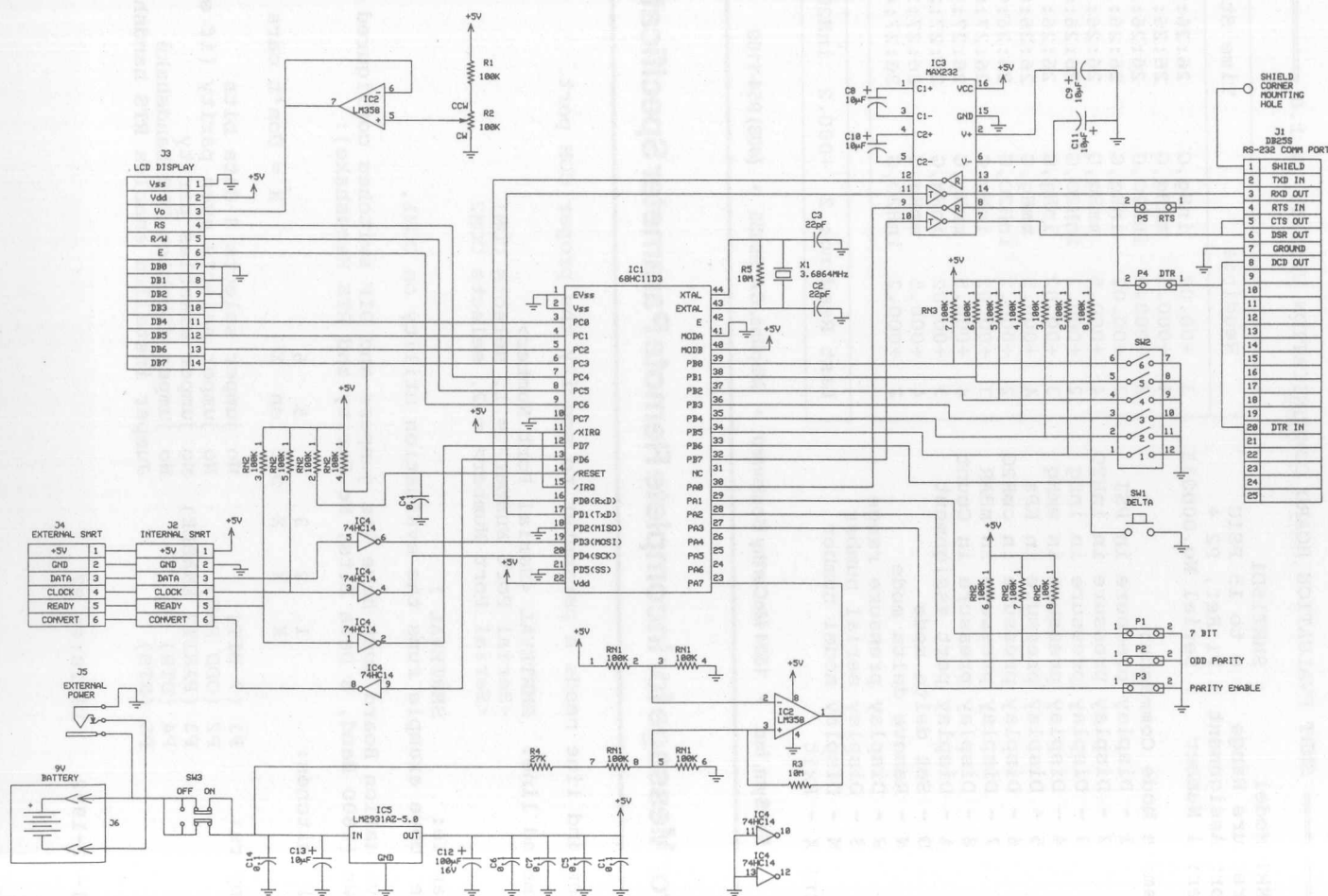
The interface connector pinout is as follows:

1 - Shield	Connected to one of the connector mounting holes
2 - Txd (in)	Serial data input to EB board
3 - Rxd (out)	Serial data output from EB board
4 - Rts - (in)	If jumpered, controls data flow to host
5 - Cts (out)	Controls data flow from host
6 - Dsr (out)	Controls data flow from host
7 - Ground	Signal ground
8 - DCD (out)	Connected to pin 20 (DTR)
20 - DTR (in)	If jumpered, control data flow to host

Note: All other pins are not connected.



SMRT-EB Layout



SMRT-EB Schematic

Typical Remote Screen Display

SMRT EVALUATION BOARD COMMUNICATION UTILITY V 1.0

SMRT Model : SMRT15D1
Pressure Range : 0 to 15 PSIG
Port Assignment : P1 Ref, P2 +
Serial Number : Serial No.000032

Remote Mode Commands:

- 1 - Display pressure in PSI
- 2 - Display pressure in inH2O
- 3 - Display pressure in inHg
- 4 - Display pressure in mmHg
- 5 - Display pressure in KPa
- 6 - Display pressure in cmH2O
- 7 - Display pressure in mBAR
- 8 - Display pressure in Count
- A - Display port assignment
- D - Set delta mode
- N - Remove delta mode
- R - Display pressure range
- S - Display serial number
- M - Display model number
- Ctrl X - Exit

Readings			Time Stamp
3	+00.02	inHg,G	26:26:06
4	+000.5	mmHg,G	26:26:17
2	+000.2	inH2O,G	26:26:28
3	+00.02	inHg,G	26:26:39
4	+000.5	mmHg,G	26:26:50
2	+000.2	inH2O,G	26:26:61
3	+00.02	inHg,G	26:26:72
4	+000.5	mmHg,G	26:26:83
2	+000.2	inH2O,G	26:26:94
3	+00.02	inHg,G	26:27:05
4	+000.5	mmHg,G	26:27:16
3	+00.02	inHg,G	26:27:27
4	+000.5	mmHg,G	26:27:38
2	+000.2	inH2O,G	26:27:49

Last Reading: 2 +000.2 inH2O,G

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Error Message for Incomplete Remote Parameter Specifications

The command line needs a parameter to specify the proper COM port.

Command line: SMRTEVAL <Serial Port Number>
<Serial Port Number> = 1, selects COM1
<Serial Port Number> = 2, selects COM2

Example: SMRTEVAL 1
The above example runs the evaluation utility on COM1.

The Evaluation Board must have its jumpers and DIP switches configured as follows (4800 Baud, 8 Data Bits, No Parity and RTS Handshake):

DIP Switches:	1	2	3	4	5	6	
	X	X	X	off	on	X	X = Don't care

Jumpers:	P1 (7 BIT)	No jumper selects 8 data bits
	P2 (ODD PAR)	No jumper selects even parity (if enabled)
	P3 (PARITY ENABLE)	No jumper disables parity
	P4 (DTR)	No jumper disables DTR handshake
	P5 (RTS)	Jumper installed enables RTS handshake

Thu 1-02-1992 16:28:44.97

A:\>

ERROR CONDITIONS

The following is a list of error conditions and there associated display format. All the error conditions blank the sign field and have priority as per the listing below. If a low battery or a no SMRT occurs during the diagnostic mode, the diagnostic mode will be terminated and the appropriate error message will be displayed.

Error	Display Format
Low Battery (1, 2)	Low Battery
No SMRT response (1)	NoSMRT
Error from SMRT	RngErr
Over Pressure	OverP
Under Pressure	UnderP

Note 1: If this error occurs during diagnostics, the diagnostic mode will be aborted and the proper error condition will be displayed.

Note 2: Low battery voltage limits are:
Low battery < 5.5V
5.5V <= ? <= 6.0V
6.0V < Battery OK

CONCLUSION

The SMRT-EB evaluation board offers a compact and versatile means to operate and evaluate SenSyms smart SMRT series pressure sensors. The evaluation board can be used in a stand alone mode or in conjunction with a PC. All necessary hardware as well as software is provided with the evaluation board. The EB board will automatically interrogate the sensor and display all the vital statistics including serial no., pressure range, and pressure port assignments. If you have any additional questions concerning the SMRT-EB please contact our applications group at the SenSym factory.

SENSYM EVALUATION BOARD ORDER FORM

Part Number	Description	Qty.
SCX-EB	Analog Output (0-5V, 1-6V)	_____
SCX-PRL8	8-Bit Parallel Output	_____
SCX-SRL8	8-Bit Serial Output	_____
SCX-LCD	3½-Digit Display	_____
SCX-EB 4.5 LCD	4½-Digit Display with Analog Output	_____
SMRT-EB	Digital Output	_____

SPECIFICATIONS

Operating Pressure Range

Sensor: SCX-"C" Series Standard

Specify SMRT Transducer to be mounted on Evaluation Board

Supply Voltage: EB: +8V to +30V or ±8V to ±22V

PRL8, SRL8; +5V only

LCD: +7V to +30V

4.5 LCD: 7V to 15V

SMRT-EB: 7V TO 15V

Output Swing/Display Range

CUSTOMER INFORMATION

Name: _____

Company: _____

Address: _____

City/State: _____

Phone Number: _____

Signed: _____ Date: _____

Make Checks Payable to: SenSym, Inc.

Return This Form to: Application Department – Eval Board
SenSym, Inc.
1804 McCarthy Blvd.
Milpitas, CA 95035

SOLID STATE SENSORS



SECTION 7 APPLICATION NOTES

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SOLID STATE SENSORS

SenSym

Pressure Transducer Accuracy in Application

Sensym

SSAN-1

After taking environmental (and hence, reliability) requirements into account, the second most important consideration for transducer selection concerns the required accuracy of the device. The concepts and formulas presented here provide a tool with which a user can calculate transducer accuracy for the specific conditions of his application.

A SYSTEM MODEL

To see how transducer performance parameters are related to system accuracy, consider the IC pressure transducer system shown in Figure 1. The problem is to determine the magnitude of error for given values of the *major input* (applied pressure) and the *minor inputs* (temperature, time and excitation voltage). The *error sources* are inherent to the transducer, but the magnitude

of error from each one may depend on the major and minor inputs to the transducer system.

To simplify our model, we first divide the error sources into two groups: those that are dependent on applied pressure and those that are not. Figure 2 gives a typical response curve for the transducer, with applied pressure, P_A , on the X-axis and output voltage signal, V_S , on the Y-axis. P_{REF} is the pressure used as a reference in measuring transducer errors. For each of Sensym's transducers, this is defined as the minimum value of the operating pressure range given in the data sheet. V_0 , the offset voltage, is the transducer output signal obtained when the reference pressure is applied. P_{MAX} is the high endpoint pressure applied to the device and this yields an output voltage, V_{MAX} . The range and span are then defined as $(P_{MAX} - P_{REF})$ and $(V_{MAX} - V_0)$ respectively. Device sensitivity, S , is the slope of the line, (Span/Range), and has units of volts/psi.

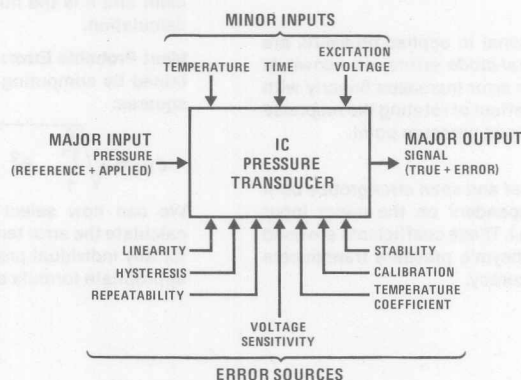
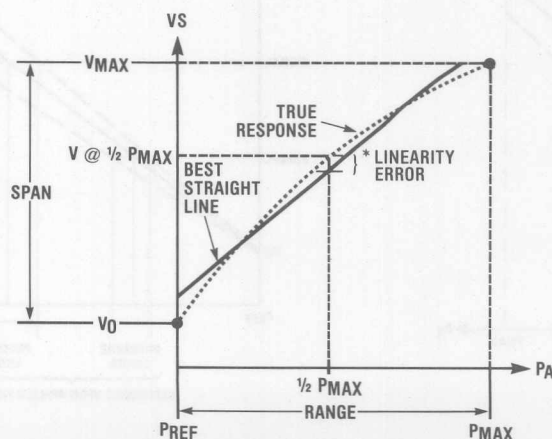


FIGURE 1



$$\begin{aligned} \text{* LINEARITY ERROR} \\ \text{\% ERROR} = \\ \frac{V @ \frac{1}{2} P_{MAX} - (V_0 + S \cdot \frac{1}{2} P_{MAX})}{2} \end{aligned}$$

$$S = \text{SENSITIVITY} = \frac{\text{SPAN}}{\text{RANGE}}$$

FIGURE 2

Because Sensym's transducers are inherently linear, the output signal can be given by:

$$V_S = V_O + S \cdot (P_A - P_{REF}) = V_O + \text{Span} \cdot \frac{(P_A - P_{REF})}{\text{Range}}$$

As a further result, the error in output signal, ΔV_S , can be expressed as:

$$\Delta V_S = \Delta V_O + \Delta \text{Span} \cdot \frac{(P_A - P_{REF})}{\text{Range}}$$

This equation shows that ΔV_O , the offset error, is independent of applied pressure while

$$\Delta \text{Span} \cdot \frac{(P_A - P_{REF})}{\text{Range}},$$

the span error, is proportional to the applied pressure range, $(P_A - P_{REF})$.

Offset errors, being independent of the major input variable (applied pressure), are equivalent to system *common-mode* errors, as shown in Figure 3. Because the offset error is the same regardless of pressure, it has the effect of translating the response line up or down, while the slope or sensitivity remains constant.

Span errors, being proportional to applied pressure, are equivalent to system *normal-mode* errors, as shown in Figure 4. Because the span error increases linearly with applied pressure, it has the effect of rotating the response line around the offset-reference pressure point.

While independent, the *offset* and *span* error groups both contain errors that are dependent on the minor input variables, as shown in Table I. These coefficients are used to specify the errors in Sensym's pressure transducers and to calculate overall accuracy.

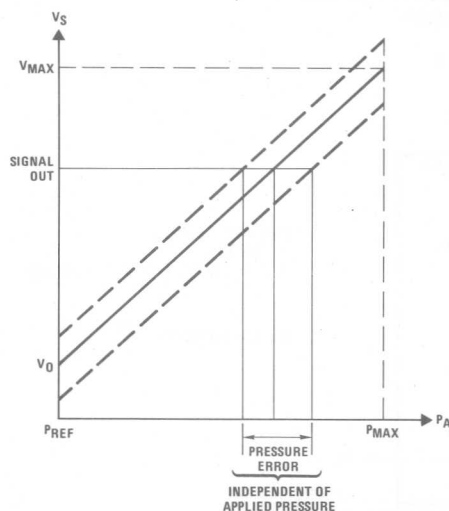


FIGURE 3

TABLE I. OFFSET AND SPAN ERRORS	
OFFSET (Common-Mode)	SPAN (Normal-Mode)
Calibration	Calibration
Repeatability	Linearity-Hysteresis-Repeatability
Stability	Stability
Temperature Coefficient	Temperature Coefficient
Excitation Voltage Coefficient	Excitation Voltage Coefficient

SYSTEM ACCURACY

With the errors divided into 2 groups of independent coefficients, we can now compute both the worst-case error and the most probable error for any IC pressure transducer system.

Worst-Case Error: The worst-case overall error ϵ_{WC} is obtained by simple addition of all applicable errors:

$$\epsilon_{WC} = \sum_{j=1}^n \epsilon_j$$

where ϵ_j is the error resulting from the j^{th} error coefficient and n is the number of error terms included in the calculation.

Most Probable Error: The most probable error ϵ_{MP} is obtained by computing the square root of the sum of the squares:

$$\epsilon_{MP} = \sqrt{\sum_{j=1}^n \epsilon_j^2}$$

We can now select the applicable error coefficients, calculate the error terms, ϵ_j , from the specifications given for any individual pressure transducer, and plug into the appropriate formula above to get system accuracy.

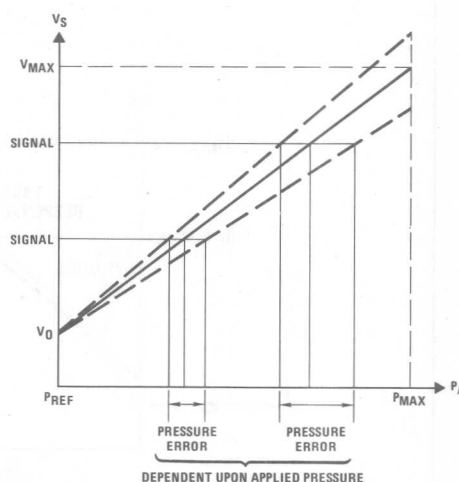


FIGURE 4

ACCURACY SPECIFICATIONS

By convention, system accuracy is expressed in the dimensions of the major input variable, in this case, psi. However, transducer accuracy is typically expressed as percent of full span (%FS). Fortunately, the transposition from one dimension to the other is analytically simple. An error coefficient expressed as %FS is changed to psi by multiplying by the range, $(P_{MAX} - P_{REF})$, of the device under consideration and dividing by 100. So the user can perform accuracy calculations in either dimension, both %FS and psi error values are given in the data sheets for linearity, hysteresis, repeatability, stability, and temperature coefficient.

Three additional points should be noted relative to the data sheet accuracy specifications. Offset calibration error is given directly as volts, since this is the parameter most users actually measure. To convert from volts to %FS, divide offset calibration error by the span voltage (typically 10V for signal-conditioned devices) and multiply by 100. If psi is desired, divide offset calibration error by the device sensitivity (mV/psi) and multiply by 1000 (mV/V). In a similar fashion, sensitivity calibration error is given directly as mV/psi. To convert to %FS, divide by the device sensitivity and multiply by 100. (Because these are linear devices, the ratio of sensitivity error to sensitivity is the same as the ratio of span error to span.) To get psi, divide sensitivity calibration by the sensitivity and multiply by the range.

Finally, supply voltage coefficient (voltage regulation error) is given directly as percentage of supply voltage change. Conversion to psi from %FS would use the same technique discussed in the first paragraph of this page.

OFFSET SPECIFICATIONS

The offset characteristics are measured at reference temperature with reference pressure applied. Although measured at the reference pressure, offset errors given in the data sheet, ΔV_O , are the same regardless of pressure and should be used in the accuracy formulas without any modification for user pressure range. They are defined as follows:

Offset Calibration: Defines the offset voltage and its maximum deviation from unit to unit, including long-term stability (1 year). The deviation is specified in volts and must be divided by full span voltage to express the error band as %FS, or divided by sensitivity to express it as psi, for accuracy calculations.

Offset Temperature Coefficient (TC_O): Defines the maximum deviation in offset voltage as temperature is varied from T_{REF} (25°C) to any other temperature, T , in the operating temperature range. It is specified as %FS/°C or psi/°C and must be multiplied by the temperature difference $|T - T_{REF}|$ to obtain the error at T as %FS or psi. For example, the maximum error for the operating temperature range of Sensym's hybrid transducers (0 to 85°C) would be:

$$TC_O \cdot (T_{MAX} - T_{REF}) = TC_O \cdot (85^\circ\text{C} - 25^\circ\text{C}) = TC_O \cdot (60^\circ\text{C}).$$

Offset temperature coefficient is factory calibrated at $25^\circ\text{C} \pm 3^\circ\text{C}$ and at $80^\circ\text{C} \pm 3^\circ\text{C}$. Any calculation of temperature related error must account for these temperature variations. Typically, errors would be calculated between two points that are at least 15°C apart.

Offset Repeatability: Defines the maximum deviation in offset voltage when applied pressure is cycled through its full range.

Offset Stability: Defines the maximum deviation in offset voltage over a one year period, during which time the pressure and temperature do not exceed their specified maximum ratings.

SPAN SPECIFICATIONS

Full span corresponds to the entire operating pressure range, $(P_{REF} \text{ to } P_{MAX})$, specified on the data sheet for each device type. This yields a span voltage, measured at the reference temperature, equal to $(V_{MAX} - V_O)$. If an application utilizes a transducer's full operating pressure range, then the span error values given in the data sheet, ΔSpan , can be plugged directly into the error formulas to determine system accuracy. However, if only part of the range is used, the data sheet span errors must be reduced proportionally, since they are a linear function of applied pressure. This is accomplished by taking the actual pressure range used in the application, dividing by the range of the device, and then multiplying each of the data sheet span errors by this ratio (which is a number between 0 and 1). Note that although application span error,

$$\Delta\text{Span} \cdot \frac{(P_A - P_{REF})}{\text{Range}}$$

is defined to include P_{REF} , this is not a user requirement. Span error is simply

$$\Delta\text{Span} \cdot \frac{\text{User Range}}{\text{Range}}$$

for any user range. The data sheet span errors, ΔSpan , are specified as follows:

Sensitivity Calibration: Sensitivity is defined as span divided by the range, $(V_{MAX} - V_O)/(P_{MAX} - P_{REF})$. Sensitivity calibration defines the maximum deviation of sensitivity from unit to unit, including long term span stability (1 year). The deviation is specified as mV/psi and must be divided by the sensitivity to express the error as %FS, or divided by the sensitivity and multiplied by the range to express it as psi, for accuracy calculations.

Span Temperature Coefficient (TC_S): Defines the maximum deviation in span voltage as temperature is varied from T_{REF} to any T in the specified operating temperature range. The coefficient is specified as %FS/°C or psi/°C and must be multiplied by the temperature difference $|T - T_{REF}|$ to obtain the span error as %FS or psi.

Linearity-Hysteresis-Span Repeatability: Linearity defines the maximum deviation of output voltage over the full operating pressure range from this BSL. Hysteresis and span repeatability define the transducer's ability to reproduce an output voltage when cycled through its full operating pressure range. This error is generally lumped with linearity error because it is small by comparison and is usually contained within any real measurement of linearity.

Span Stability: Defines the maximum deviation in span voltage over a one year period during which time pressure and temperature do not exceed their specified maximum ratings.

SYSTEM ACCURACY CALCULATIONS

Voltage Regulation

In the example calculations that follow, we will assume that user excitation voltage is sufficiently regulated so as to make the voltage regulation error, ϵ_{VR} , negligible ($\leq 0.1\%$ FS). ϵ_{VR} is an output signal change due solely to a change in excitation voltage. The percent regulation required to satisfy this condition is derived as follows. For signal-conditioned devices, ϵ_{VR} is given by:

$$\epsilon_{VR} = 0.5\% \cdot \Delta V_e$$

where 0.5% is the specified transducer output voltage change to excitation voltage change and ΔV_e is the excitation voltage deviation [from nominal (15V)]. To keep the regulation error below 0.1% FS, the required external power supply regulation is given by:

$$\frac{\Delta V_e}{V_e} = \left(\frac{1}{0.5\%} \right) \cdot \left(\frac{\epsilon_{VR}}{V_e} \right) = 200 \cdot \left(\frac{\epsilon_{VR}}{\text{Span}} \right) \cdot \left(\frac{\text{Span}}{V_e} \right)$$

$$\text{Since } \frac{\epsilon_{VR}}{\text{Span}} = 0.1\%,$$

$$\frac{\Delta V_e}{V_e} = 20\% \cdot \left(\frac{\text{Span}}{V_e} \right)$$

For Span = 10V and $V_e = 15V$,

$$\frac{\Delta V_e}{V_e} = 20\% \cdot \left(\frac{2}{3} \right) = \pm 13\% \text{ Regulation}$$

which holds for any signal-conditioned pressure transducer.

For monolithics, which do not have any internal regulation or signal conditioning, the formulation is not quite as neat since output characteristics vary from device to device. However, as an approximation, it can be assumed that output signal changes are roughly proportional to changes in excitation voltage. Therefore, to ensure $\epsilon_{VR} \leq 0.1\%$ FS would require a power supply with $\leq 0.1\%$ regulation.

If the signal conditioning or monolithic regulation requirements calculated above are met, then regulation error can be eliminated from essentially all error calculations, with the possible exception of ultra-high accuracy applications. However, the greater the deviation from these requirements, the more necessary it becomes to include ϵ_{VR} in the accuracy calculations. Since both ΔV_O and ΔSpan are affected, ϵ_{VR} would be included in both segments of the error calculation.

Interchangeable vs. Calibrated Accuracy

Interchangeable Accuracy: In calculating overall accuracy, the first question is whether each pressure transducer will be field calibrated upon installation or replacement. If you're going to just plug it in with no adjustments, you'll need the *interchangeable accuracy*, which allows for unit-to-unit calibration errors. In this case, you include Sensym's calibration errors but exclude stability error (the specified calibration error includes both calibration and stability errors). ϵ_i , the overall error allowing for direct exchange of transducers of the same type, includes calibration, TC, linearity, hysteresis, and repeatability errors.

Calibrated Accuracy: If you intend to calibrate each device upon installation, you will want to use the *calibrated accuracy*, ϵ_C , which holds only for one specific transducer. The calibrated overall accuracy excludes Sensym's calibration errors, but includes all other appli-

cable specified errors including stability, TC, linearity, hysteresis, and repeatability.

Example Calculations

The LX1604D is chosen to show how error calculations would be performed for a typical pressure transducer under various conditions. Analogous procedures apply to any Sensym IC pressure transducer and can be extended for use in evaluating errors in a complete pressure system.

Table II is a reproduction of the applicable LX1604D data on page 5-5. The LX1604D operating pressure range is -15 psid to +15 psid. Therefore, $P_{REF} = -15$ psid, $P_{MAX} = +15$ psid, and $\text{Range} = (P_{MAX} - P_{REF}) = 30$ psid. V_O (at -15 psid) = 2.5V (from the offset calibration column) and $V_{MAX} = V_O + S \cdot (P_{MAX} - P_{REF}) = 2.5 + (0.333)(30) = 12.5V$ (where the sensitivity value is obtained from the sensitivity calibration column and converted into V/psi). Therefore, $\text{Span} = V_{MAX} - V_O = 10V$.

To be consistent with Table I, the data divides the error terms into two categories: those for offset, ΔV_O , and those for span, ΔSpan . Table II further identifies each component of error as follows: ΔV_{O1} is the offset calibration error, ΔV_{O2} is the offset temperature coefficient error, ΔV_{O3} is the offset repeatability error, and ΔV_{O4} is the offset stability error. Likewise, sensitivity (and thus span) calibration error is ΔSpan_1 , ΔSpan_2 is the span temperature coefficient error, ΔSpan_3 is the combined linearity, hysteresis, and repeatability error, and ΔSpan_4 is the span stability error. As mentioned previously, where appropriate, both %FS and psi errors are included.

The following calculations are performed using %FS error values. However, completely analogous results would be obtained using psi errors (psi results for each calculation are included for reference purposes).

Maximum Error—Case I

The maximum possible error would occur for the case where the full temperature and pressure ranges are used. Under these temperature conditions, each temperature coefficient is converted to %FS by multiplying the data sheet errors by $(T_{MAX} - T_{REF}) = (85^\circ\text{C} - 25^\circ\text{C}) = 60^\circ\text{C}$. Then:

$$\Delta V_{O2} = 0.03 \times 60 = 1.8\% \text{ FS}$$

and

$$\Delta \text{Span}_2 = 0.03 \times 60 = 1.8\% \text{ FS}$$

Since the full pressure range is being used, it is not necessary to decrease any of the span errors proportionally. The %FS table values would be plugged directly into the accuracy formulas.

The only conversion remaining is to change calibration errors in the data to %FS. Offset calibration is converted by dividing by span voltage (10V) and multiplying by 100 while sensitivity calibration is converted by dividing by sensitivity (333 mV/psi) and multiplying by 100.

$$\Delta V_{O1} = \frac{100(0.35)}{10} = 3.5\% \text{ FS}$$

and

$$\Delta \text{Span}_1 = \frac{100(6.7)}{333} = 2\% \text{ FS}$$

Having all %FS values, it is now possible to calculate ϵ_i , interchangeable overall error, and ϵ_C , calibrated overall error, worst-case and most probable error values.

TABLE II. LX1604D PRESSURE TRANSDUCER SPECIFICATIONS

Offset Characteristics						
Offset Calibration $V \pm \Delta V_{O1}$	Temperature Coefficient ΔV_{O2}		Repeatability ΔV_{O3}		Stability ΔV_{O4}	
	$\pm \% \text{FS}/^{\circ}\text{C}$	$\pm \text{psi}/^{\circ}\text{C}$	$\pm \% \text{FS}$	$\pm \text{psi}$	$\pm \% \text{FS}$	$\pm \text{psi}$
2.5 ± 0.35	0.03	0.009	0.4	0.12	1.7	0.5
Span Characteristics						
Sensitivity Calibration mV/psi ΔSpan_1	Temperature Coefficient ΔSpan_2		Linearity Hysteresis & Repeatability ΔSpan_3		Stability ΔSpan_4	
	$\pm \% \text{FS}/^{\circ}\text{C}$	$\pm \text{psi}/^{\circ}\text{C}$	$\pm \% \text{FS}$	$\pm \text{psi}$	$\pm \% \text{FS}$	$\pm \text{psi}$
333 ± 6.7	0.03	0.009	0.67	0.20	0.3	0.1

For interchangeable overall error, offset stability, ΔV_{O4} , and span stability, ΔSpan_4 , are eliminated. The remaining offset and span errors are plugged into the ϵ_{WC} and ϵ_{MP} formulas to yield

Worst-case: ϵ_{WCI}

$$= \Delta V_{O1} + \Delta V_{O2} + \Delta V_{O3} + \Delta \text{Span}_1 + \Delta \text{Span}_2 + \Delta \text{Span}_3$$

$$= \underbrace{(3.5 + 1.8 + 0.4)}_{\text{Offset}} + \underbrace{(2 + 1.8 + 0.67)}_{\text{Span}} = \pm 10.17\% \text{FS}$$

Most probable: ϵ_{MPI}

$$= \sqrt{\Delta V_{O1}^2 + \Delta V_{O2}^2 + \Delta V_{O3}^2 + \Delta \text{Span}_1^2 + \Delta \text{Span}_2^2 + \Delta \text{Span}_3^2}$$

$$= \sqrt{\underbrace{3.5^2 + 1.8^2 + 0.4^2}_{\text{Offset}} + \underbrace{2^2 + 1.8^2 + 0.67^2}_{\text{Span}}} = \pm 4.83\% \text{FS}$$

This corresponds to ± 3.05 psid and ± 1.45 psid respectively.

For calibrated overall error, both calibration errors, ΔV_{O1} and ΔSpan_1 , are eliminated from the above calculation and the two stability errors, ΔV_{O4} and ΔSpan_4 , are inserted.

Worst-case: ϵ_{WCC}

$$= \Delta V_{O2} + \Delta V_{O3} + \Delta V_{O4} + \Delta \text{Span}_2 + \Delta \text{Span}_3 + \Delta \text{Span}_4$$

$$= \underbrace{(1.8 + 0.4 + 1.7)}_{\text{Offset}} + \underbrace{(1.8 + 0.67 + 0.3)}_{\text{Span}} = \pm 6.67\% \text{FS}$$

Most probable: ϵ_{MPC}

$$= \sqrt{\Delta V_{O2}^2 + \Delta V_{O3}^2 + \Delta V_{O4}^2 + \Delta \text{Span}_2^2 + \Delta \text{Span}_3^2 + \Delta \text{Span}_4^2}$$

$$= \sqrt{\underbrace{1.8^2 + 0.4^2 + 1.7^2}_{\text{Offset}} + \underbrace{1.8^2 + 0.67^2 + 0.3^2}_{\text{Span}}} = \pm 3.17\% \text{FS}$$

This corresponds to ± 2.00 psid and ± 0.95 psid respectively.

Reducing Temperature Errors—Case II

Since the temperature coefficients are two of the main error components, a reduced temperature range can greatly reduce overall error. For 80% effective temperature com-

pensation (reducing effective range from 60°C to 12°C), the offset and span temperature coefficients would be

$$\Delta V_{O2} = 0.03 \times 12 = 0.36\% \text{FS}$$

and

$$\Delta \text{Span}_2 = 0.03 \times 12 = 0.36\% \text{FS}$$

The interchangeable overall errors would then be reduced to

Worst-case: ϵ_{WCI}

$$= (3.5 + \underbrace{0.36}_{\text{Reduced TC Errors}} + 0.4) + (2 + \underbrace{0.36}_{\text{Reduced TC Errors}} + 0.67) = \pm 7.29\% \text{FS}$$

Most probable: ϵ_{MPI}

$$= \sqrt{3.5^2 + 0.36^2 + 0.4^2 + 2^2 + 0.36^2 + 0.67^2}$$

$$= \pm 4.14\% \text{FS}$$

This corresponds to ± 2.19 psid and ± 1.24 psid respectively, reduced from ± 3.05 psid and ± 1.45 psid in Case I.

A corresponding improvement is achieved for the calibrated accuracy:

Worst-case: ϵ_{WCC}

$$= (\underbrace{0.36 + 0.4 + 1.7}_{\text{Reduced TC Errors}}) + (\underbrace{0.36 + 0.67 + 0.3}_{\text{Reduced TC Errors}}) = \pm 3.79\% \text{FS}$$

Most probable: ϵ_{MPC}

$$= \sqrt{0.36^2 + 0.4^2 + 1.7^2 + 0.36^2 + 0.67^2 + 0.3^2}$$

$$= \pm 1.96\% \text{FS}$$

This corresponds to ± 1.14 psid and ± 0.59 psid respectively, reduced from ± 2.00 psid and ± 0.95 psid by 80% effective temperature compensation.

Reduced Pressure Range—Case III

When the full specified pressure range of a particular device is not being used, all span errors should be reduced by the ratio R, where R is defined as:

$$R = \frac{\text{User Range}}{\text{Device Specified Range}}$$

Assume, for example, that the user application is for +5 psid to +15 psid. Then $R = 10 \text{ psid}/30 \text{ psid} = 0.333$, and each application span error would be

$$\Delta \text{Span}_1 = 2 \times 0.333 = \pm 0.67\% \text{FS}$$

$$\Delta \text{Span}_2 = 0.03 \times 0.333 = \pm 0.01\% \text{FS}/^{\circ}\text{C}$$

$$\Delta \text{Span}_3 = 0.67 \times 0.333 = \pm 0.22\% \text{FS}$$

$$\Delta \text{Span}_4 = 0.3 \times 0.333 = \pm 0.1\% \text{FS}$$

If Case II conditions above are maintained, then the interchangeable overall errors would now be reduced to

Worst-case: ϵ_{WCI}

$$= (3.5 + 0.36 + 0.4) + (\underbrace{0.67 + 0.12 + 0.22}_{\text{Reduced Span Errors}}) = \pm 5.27\% \text{FS}$$

Most probable: ϵ_{MPI}

$$= \sqrt{3.5^2 + 0.36^2 + 0.4^2 + 0.67^2 + 0.12^2 + 0.22^2}$$

$$= \pm 3.61\% \text{FS}$$

This corresponds to ± 1.58 psid and ± 1.08 psid respectively, reduced from ± 2.19 psid and ± 1.24 psid in Case II.

NOTE: The reduced pressure range decreases span error values only. Offset errors remain unchanged!

For calibrated overall error

Worst-case: ϵ_{WCC}

$$= (0.36 + 0.4 + 1.7) + \underbrace{(0.12 + 0.22 + 0.1)}_{\text{Reduced Span Errors}} = \pm 2.90\% \text{ FS}$$

Most probable: ϵ_{MPC}

$$= \sqrt{0.36^2 + 0.4^2 + 1.7^2 + 0.12^2 + 0.22^2 + 0.1^2} = \pm 1.80\% \text{ FS}$$

This corresponds to ± 0.87 psid and ± 0.54 psid, respectively, reduced from ± 1.14 psid and ± 0.59 psid in Case II, by using 1/3 of the LX1604D pressure range.

Auto-Reference Compensation—Case IV

A powerful, easy-to-use, and generally applicable technique, auto-referencing, can often eliminate all offset errors by period sampling of the offset voltage at reference pressure. With this technique, (see Section 6), only the span errors apply. Again, using the LX1604D specifications and assuming all Case III conditions hold, the interchangeable accuracy is:

Worst-case: ϵ_{WCI}

$$= \underbrace{(0.67 + 0.12 + 0.22)}_{\text{Span Errors}} = \pm 1.01\% \text{ FS}$$

Most probable: ϵ_{MPI}

$$= \sqrt{0.67^2 + 0.12^2 + 0.22^2} = \pm 0.72\% \text{ FS}$$

This corresponds to ± 0.30 psid and ± 0.22 psid, respectively, reduced from ± 1.58 psid and ± 1.08 psid in Case III.

Calibrated overall error would be

Worst-case: ϵ_{WCC}

$$= \underbrace{(0.12 + 0.22 + 0.1)}_{\text{Span Errors}} = \pm 0.44\% \text{ FS}$$

Most probable: ϵ_{MPC}

$$= \sqrt{0.12^2 + 0.22^2 + 0.1^2} = \pm 0.27\% \text{ FS}$$

This corresponds to ± 0.13 psid and ± 0.08 psid, respectively, reduced from ± 0.87 psid and ± 0.54 psid in Case III.

Auto-Reference + Temperature Control—Case V

For very high accuracy applications, both auto-referencing and complete temperature range reduction may prove valuable. In these cases, the additional temperature compensation may take the form of a temperature-controlled chamber designed to hold temperature within a few degrees of T_{REF} (which may be shifted to a higher temperature to allow use of an oven). In such a case, the only errors included are linearity, hysteresis, span repeatability and either span calibration or span stability. For interchangeable accuracy, span calibration error is included:

Worst-case: ϵ_{WCI}

$$= \underbrace{(0.67 + 0.22)}_{\text{Span Errors without TC}} = \pm 0.89\% \text{ FS}$$

Most probable: ϵ_{MPI}

$$= \sqrt{0.67^2 + 0.22^2} = \pm 0.71\% \text{ FS}$$

This corresponds to ± 0.27 psid and ± 0.21 psid respectively.

For calibrated accuracy, span stability error is including:

Worst-case: $\epsilon_{WCC} = \underbrace{(0.22 + 0.1)}_{\text{Span Errors without TC}} = \pm 0.32\% \text{ FS}$

Most probable: $\epsilon_{MPC} = \sqrt{0.22^2 + 0.1^2} = \pm 0.24\% \text{ FS}$

This corresponds to ± 0.10 psid and ± 0.07 psid respectively.

Periodic Span Calibration—Case VI

With overall error down to a fraction of a psi, resulting from auto-referencing and temperature control, the periodic recalibration of span may become worthwhile. Since the span stability error is a slowly aging variation of span voltage, a periodic recalibration may well reduce this error by an order of magnitude. This procedure eliminates calibration error, so only calibrated accuracy applies.

Worst-case: $\epsilon_{WCC} = \underbrace{(0.22 + 0.01)}_{\text{Reduced Stability Error}} = \pm 0.23\% \text{ FS}$

Most probable: $\epsilon_{MPC} = \sqrt{0.22^2 + 0.01^2} = \pm 0.22\% \text{ FS}$

This corresponds to ± 0.07 psid in both cases.

Linearity Compensation—Case VII

For ultra-high accuracy applications, the remaining error, linearity-hysteresis-span repeatability, must be reckoned with. The hysteresis and repeatability components of this coefficient are so small as to approach the noise in the operational amplifier included in the signal-conditioned IC pressure transducer. This noise is about 0.4%FS for a 1 kHz bandwidth and may require narrow band filter techniques if ultra-high accuracy is to be achieved. We do know, however, that the linearity error is a large fraction of the remaining error, perhaps as high as 90%, and that it can be successfully compensated via curve-fitting techniques to reduce overall calibrated error to about $\pm 0.1\% \text{ FS}$, worst-case.

SUMMING IT UP

The foregoing offers the reader a quantitative technique for separating transducer errors and evaluating their contribution to system accuracy, as well as describing several methods for system optimization. It is hoped that this will encourage the transducer user to take a closer look at system requirements as they relate to each of the parameters and optimization techniques discussed, thereby allowing him to make optimum accuracy/cost design tradeoffs. Too often, transducer application specifications are unnecessarily tight, simply because an analysis similar to the one performed above has not been done. The result of this over-specification is unnecessary cost.

Basics of Auto-Referencing

SenSym

SSAN-2

Auto-referencing is a family of powerful techniques used to compensate time and temperature errors by periodic correction of the output signal with respect to one or more reference pressure levels. The error correction circuits are usually simple and low in cost, and at least one pressure level suitable for referencing is usually accessible or can be easily produced. So, it's natural to want to use auto-referencing, since the alternative (an expensive precision pressure transducer) is usually more trouble than it's worth and definitely more expensive than an auto-referenced pressure transducer with comparable accuracy. While it's never wise to declare that a technique is "universal", some techniques are so powerful that it becomes easier to cite instances where the technique should not be used than where it should. Auto-referencing is just such an "almost universal" technique. Why then is this technique not more widely used with transducers? Traditionally, transducer users and producers are "linear/analog" oriented people, to whom "digital" people are those other guys in the soft world. Factually, analog approaches to auto-referencing are less cost effective. So, there's a natural reluctance for analog people to employ digital circuitry for an analog function. Yet, all mensuration theorists and educators highly recommend the technique. Therefore, the message is...get on board, fellow analogers, digital auto-referencing is good for you.

Which pressure transducer users should *not* use a common-mode auto-referencing circuit? In applications involving a short measurement cycle, where the zero point is either read or manually adjusted at the start of the cycle,

an auto-referencing circuit is of no value. In acoustic measurements where the transducer is AC coupled such that DC or steady state response is of little value, common-mode auto-referencing won't help. In all other applications, common-mode auto-referencing yields the optimum accuracy for the lowest cost.

COMMON-MODE AUTO-REFERENCING — EASY AND EFFECTIVE

Common-mode errors are generally the largest (especially at lower pressures, where it really counts in some applications) and therefore give way to the greatest accuracy improvement when auto-referenced. They are also the easiest to auto-reference as shown in Figure 2, since all that's required is to sample the signal at reference pressure and subtract the error from the signal at any "measure" pressure. This is expressed by the formula

$$V_{SCM} = V - \Delta V_0$$

where V is any measure pressure signal, ΔV_0 is the error pressure signal and V_{SCM} is the output signal corrected for common-mode error by subtracting the error from the measure signal. As seen in Figure 2, no slope correction is involved.

The basic auto-reference functions required to implement this formula are shown in Figure 3. They include a switch, a sample-and-hold, and interconnecting logic for synchronizing with the measure-reference cycle.

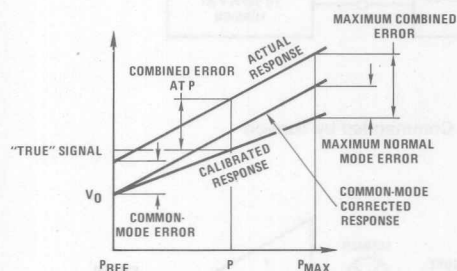


FIGURE 1. Transducer Errors

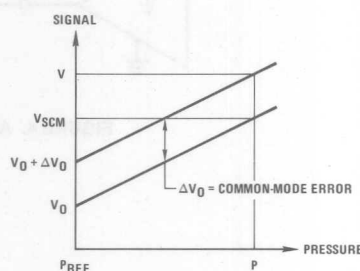


FIGURE 2. Common-Mode Error Correction

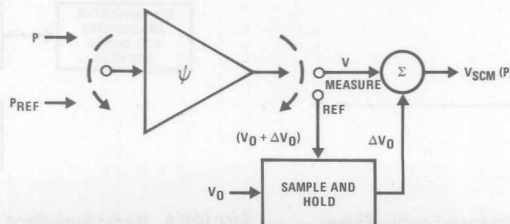


FIGURE 3. Basic Common-Mode Auto-Reference Functions

What's the best way to use auto-referencing? The correct, but imprecise, answer is...as often as you can. The object is to have those measurements of greatest interest closest in time to an auto-reference command. The kind of duty cycle naturally best suited to auto-referencing is "short repeated cycles", each containing a reference point. Another well suited kind of duty cycle is a short interest period immediately preceded by a referencing point, but followed by a long no-interest period. In either case, a measurement point of interest is within several hours of the preceding reference point. Most applications have duty cycles that are in one of the two aforementioned "naturally well suited for auto-referencing" categories. Equally important, many applications that have duty cycles not naturally well suited can be converted to the short repeated cycle situation with relative ease if the value of doing so is recognized by the designer early enough. The simplest of the best suited applications involve things that go up, then go down, and then rest awhile. Ideally, the pressure increases rapidly to the range of interest, hovers at the measurement condition, decreases quickly, and hovers at the reference condition.

Some applications very closely resemble the ideal description. For example, a weighing scale is ideal. Also ideal are filling washing machines, beer bottles, and toilet tanks. Another ideal category is pressure sumps such as tire pressure, oil pressure, and blood pressure. In these cases, the measurement apparatus is usually turned-on at a reference condition before experiencing the measurement condition of interest. Less ideal, but certainly improved by auto-referencing, are flow measure-

ment and control applications. Examples are fuel pumps, pulmonometers, and even machines that smoke cigarettes. In these cases, the flow rate is zero at some point in a relatively short cycle...usually at turn-on.

The trick is to cause the command signal at the right time. The best time is after the transducer is warmed up and when the application is hovering at a reference condition. All the previous examples were of a type wherein the reference condition exists at and shortly after turn-on. This makes life easy. If the warm-up error is of little concern, then the turn-on signal can be used directly as the command signal, as shown in *Figure 4*.

Other ways of getting the required momentary command signals often present themselves as appropriate to the application. For example, in weighing systems, some displacement is inherent just as the load is applied to the scale pan barely before pressure build-up, an invitation to use a mechanical switch.

SIMPLE CIRCUIT FOR SIMPLEST CASE

The momentary switch referred to for the simplest case, forms an enable signal for input to the command gate, *Figure 5*.

The basic functions of an auto-reference circuit are shown in *Figure 6*.

The leading edge, negative transition of the enable signal resets the control latch and resets the counter to zero. While in the low state, the enable signal inhibits the

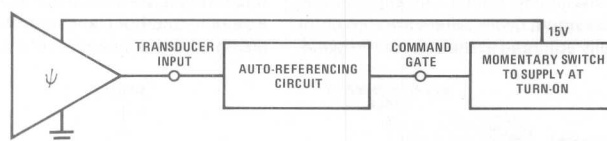


FIGURE 4. Auto-Reference Commanded by Turn-on

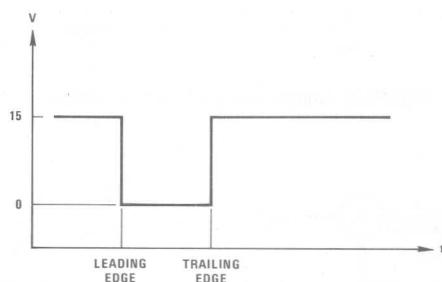


FIGURE 5. Typical Auto-Reference Enable Signal

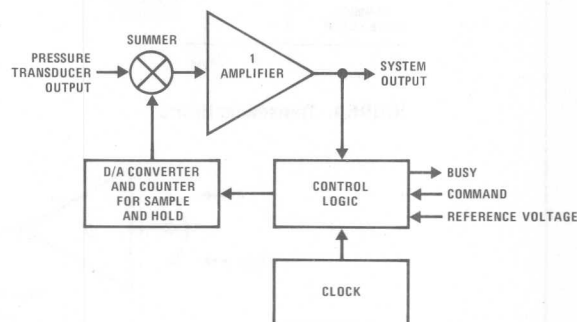


FIGURE 6. Basic Functions of Digital Auto-Reference Circuit

counter from accepting input pulses to allow time for stabilization of pressure. The referencing sequence is initiated on the trailing edge, positive transition of the enable signal. The D to A converter is used as an infinite sample-and-hold as well as a programmable voltage source, supplying and maintaining the desired correction voltage. The output of the transducer is summed with the auto-reference correction voltage at the summing junction of the first amplifier. The circuit is shown in Figure 7.

The "bit" rating of the (D/A) determines the resolution of the output signal. The quality of regulation of the reference voltage applied to the (D/A) determines the system stability. Thus, these easily attained circuit parameters take control of the transducer system's key accuracies. The control logic resets the (D/A), steers clock pulses into the (D/A) until the system output is at reference voltage and sends a busy signal to the sequence logic (Figure 7).

SIMPLE PLUMBING FOR TOUGHER CASE

Duty cycles fall into two main categories...*batch process* and *continuous process*. In batch process, the reference condition generally exists right at process turn-on. For example, a weighing scale would be turned on before the load is applied and would be at reference conditions before and after loading. Similarly, the washing machine water level is zero both before and after the duty cycle and turn-on coincides with zero level. A sphygmomanometer is inflated during blood pressure measurement and is deflated both before and after duty cycle and in particular

at turn-on. Whether at turn-on or not, at some point in a batch process, there is an obvious reference condition. In continuous process, the reference condition generally doesn't exist at all unless plumbed. In these cases, a solenoid is actuated as often as application allows. Generally, a cyclic pattern is developed. A clock circuit is often involved. In all cases, solenoid actuation causes reference pressure, so that auto-reference command is in sync with solenoid actuation.

Suppose you needed to know the flow rate of a river at various locations along its length. You'd need to know the cross sectional area, of which depth is a variable factor... and you'd need to know the flow velocity. Pressure transducers are likely choices for sensing both variables. Clearly, this application lacks features of the "naturally well suited for auto-referencing" kind. Unlike the toilet tank, there is no time at which the depth and velocity are known. In the previously described applications, there was always a known reference condition when the user consciously or inadvertently gave the command signal immediately preceding a measurement condition. In other words, the user knew when the measurand was at reference condition...thereby commanding auto-referencing at the reference condition and reading or controlling at the measurement condition. In this new breed of application, we need to access the reference condition rather than lay in wait. That is, there is a reference condition available. It won't walk up and attach itself to our pressure tube — but it is accessible if plumbed.

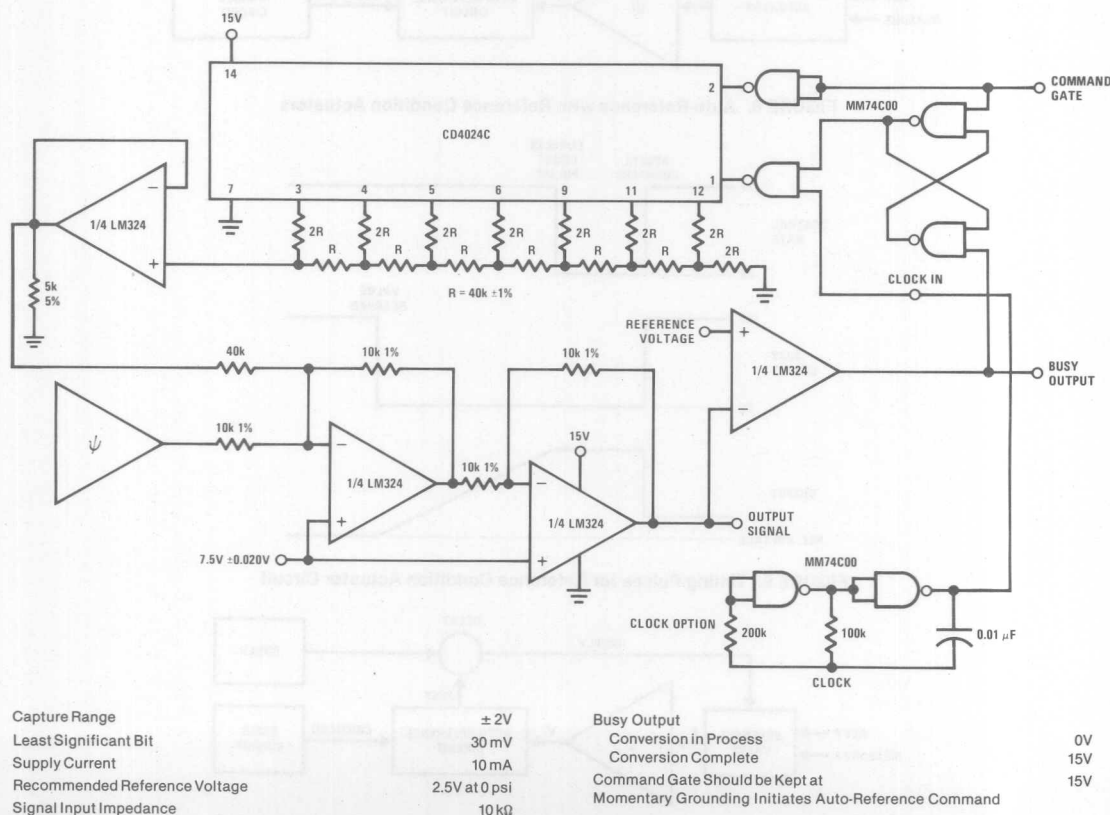


FIGURE 7. Auto-Reference Circuit with D/A Converter

ACCESS PLUMBING AND ACTUATION

In addition to the "transducer/auto-reference/enable" system for the simple case, a reference condition actuator is required. The actuator can be turned-on by the user, or by some usage condition (like power-up), or by a timer circuit (clock). Some actuators are self-limiting in duration... others must be turned-off after auto-referencing, as shown in Figure 8.

Busy signal duration is substantially longer than is enable signal duration so as to allow reference pressure stabilization and time to reach reference signal, as shown in Figure 9.

Consider the depth measurement in our river. Suppose we use either a gage or absolute pressure transducer near the bottom with a vent tube to the surface (along with the bundle of wires). A 3-way solenoid valve plumbed between the transducer inlet port, the water, and the vent tube... serves as the reference actuator. A timer circuit acts as enabler (Figure 10).

Consider the velocity measurement in that river. This requires a differential pressure transducer. A 2-way solenoid valve plumbed between the two inlet ports of the transducer serves as reference actuator, as shown in Figure 11.

COMMANDING AUTO-REFERENCING

Starting

Now that we know when to auto-reference, how do we command it? Electrically, the command gate of the auto-reference circuit must see a positive voltage transient exceeding a threshold voltage and a return to a voltage below the threshold. The model of a momentary switch from ground to supply, as shown in Figure 12, is practical but overly restrictive. There are three levels of sophistication that can be used to command auto-reference.

The simplest way is *manual command*. A momentary contact pushbutton switch can be used that turns on auto-reference alone or in conjunction with display or even with total electronics. If the switch function used approximates a step, as would be the case for bias turn-on, then the signal must be differentiated by the command circuit to initiate the zeroing sequence.

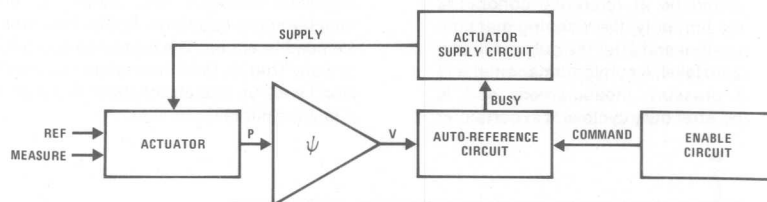


FIGURE 8. Auto-Reference with Reference Condition Actuators

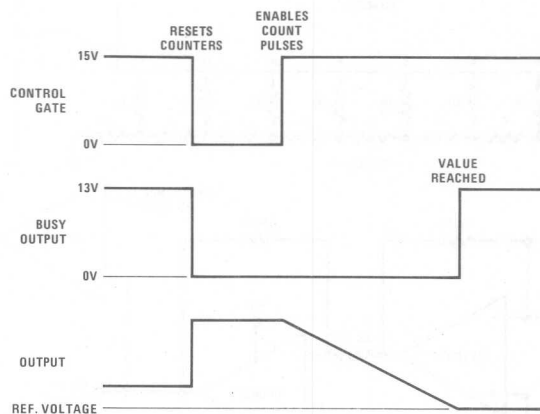


FIGURE 9. Timing Pulses for Reference Condition Actuator Circuit

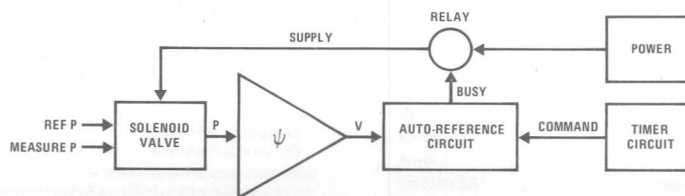


FIGURE 10. Timer-Actuated Circuit — Single-Port Transducer

More elegant is the *semiautomatic command*. Consider a stepping switch. It could be manually initiated in a manner described for manual command. But, it could then sequence through such steps as solenoid actuation, followed by auto-reference command, followed by return to measurement mode. A shift register or a sequence counter would be a more electronic and less expensive substitute for the stepping switch.

Most sophisticated is the *automatic command*. Consider now a stepping switch that actuates the solenoid, commands the auto-reference, then triggers the timing circuit that upon expiration will restart the sequence, and finally returns to measurement mode. Again, the register or counter can substitute for the switch. However, consider a stepping switch that also contains both the timing circuit and the auto-reference circuit and even drives the display. This, of course, is a microprocessor.

Sequencing

The actuation and auto-reference command block diagram is shown in Figure 13. Within the sequence function, coincidence logic assures that the start signal and reference conditions occur simultaneously. Coincidence detection is commonly provided by an "exclusive OR" circuit like an NSC MM74C86 CMOS. Steering logic receives the coincidence signal and the auto-reference completion (end busy) signal and instigates stepping. Steering commonly employs "NAND gates" and "Flip Flops" like NSC MM74C00 CMOS and NSC MM74C74

CMOS respectively. Stepping logic takes signals from the steering logic and directs the output function. If a timer is controlling the start function, the stepper may also be used to reset the timer, thereby directing sequence. Stepping commonly uses "shift registers" like NSC MM74C164 CMOS or "counter/dividers" like NSC MM5622A CMOS. The entire sequence function controls the output function.

Accuracy

The beauty of the auto-reference technique can now be examined in terms of system accuracy and resolution. The common-mode errors contributed by the pressure transducer, which appear as a reference drift due to various effects and a lack of reference resolution, are totally replaced by the accuracy limits of the auto-reference circuit. Reference drift is solely a function of voltage regulation since it is as stable as the reference voltage. That error can be made virtually zero. Resolution is a function of the "bit" rating of the D/A converter. Auto-reference circuits can vary greatly in cost depending on such application requirements as offset capture range and resolution. If the pressure transducer is properly chosen, the circuit can reduce offset (common-mode) error to from 1/4% span to 1/2% span, leaving only the substantially less severe sensitivity based (normal-mode) transducer errors to contribute to system error... not a bad trick for the price of an inexpensive circuit and possibly a solenoid valve. Needless to say, we at Sensym recommend auto-referencing for everybody.

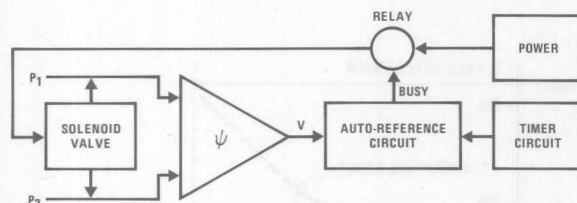


FIGURE 11. Timer-Actuated Circuit — Dual-Port Transducer

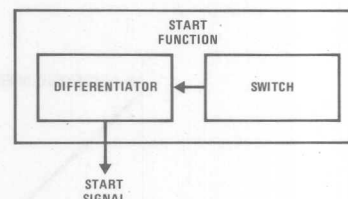


FIGURE 12. Momentary Switch Start Signal

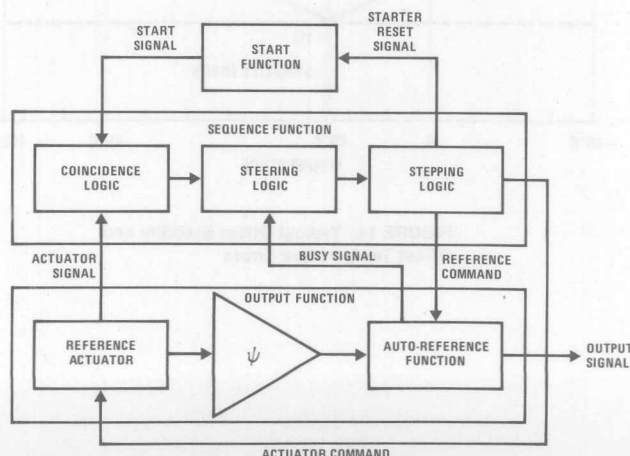


FIGURE 13. Auto-Reference Sequencing Logic

LIMITED AUTO-REFERENCING...EXAMPLE ANALYSIS

Example Conditions:

1. System to operate over an extended temperature range (-40°C to $+105^{\circ}\text{C}$).
2. System monitors both pressure and temperature.
3. Auto-referencing is to be employed at start-up when pressure is known to be zero. Temperature at auto-reference condition can be over the full operating range and is known.
4. Interchangeability is required.

Example Analysis:

1. A Look at the System without Auto-Referencing...

The sole purpose of the auto-referencing feature of this system is to periodically eliminate pressure offset errors due to time. These can be associated with the sensor itself or be part of the sensor signal conditioning. Therefore, the entire focus of this analysis will address only offset errors due to stability of offset over time and temperature related errors. *Figure 14* displays the two key offset error terms of this system without auto-referencing.

This is for the LX1830GZ device. A constant error budget for stability for one year is taken at one percent full-scale. Additional error must be added for temperature related error associated with device temperatures different from the factory calibrated temperature of 25°C .

This error is, an additional error, added at a rate of 0.02% full-scale per degree centigrade from 25°C . For this device these two errors contribute slightly greater than 2% full-scale error over the specified operating temperature range and would contribute in excess of 3% full-scale error over extended operating temperature range of the device. Temperature errors are added at twice the rate outside the specified operating temperature range.

2. A Look at the System with "Blind" Auto-Referencing...

Figure 15 has added two curves, auto-reference #1 and auto-reference #2 to *Figure 14* curves. Auto-reference #1 is the resulting error due to auto-referencing occurring at maximum specified operating temperature. Auto-reference #2 is the resulting error due to auto-referencing occurring at maximum extended operating temperature. In auto-reference #1 case, more error has been added to the system when operated below t_1 ($\sim 35^{\circ}\text{C}$) than was eliminated, as much as 0.6% full-scale. For auto-reference #2 additional error is added when the system is operated below t_2 ($\sim 55^{\circ}\text{C}$). A person may attempt to eliminate this error by using the temperature to remove temperature error as well. This would eliminate interchangeability, since temperature compensation varies from device to device and would be extremely costly to implement in software.

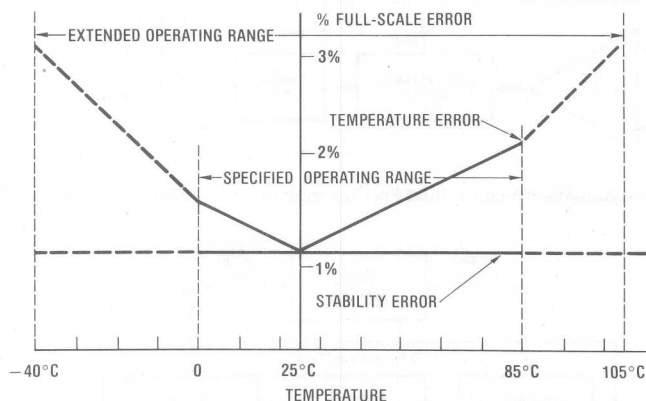


FIGURE 14. Typical Offset Stability and Offset Temperature Errors

Example Solution...

Figure 16 shows effects of auto-referencing over a limited temperature range, the auto-reference temperature band. Since the temperature is known, it becomes a simple matter to set an auto-reference "enable" condition for the system. In the "enable" state auto-referencing takes place, if not "enabled" then no auto-referencing can occur. The auto-reference temperature band must be set to "enable" auto-referencing on a periodic basis.

Close:

Worse case conditions for this example were chosen by having auto-referencing occur at maximum temperatures. Most systems will have auto-referencing occurring at a low temperature and then the system will heat up during operation. A similar analysis is still valid in that case. Except for this temperature difference this example is very similar to what is desired for pressure monitoring systems of vehicles such as diesel or gasoline engines.

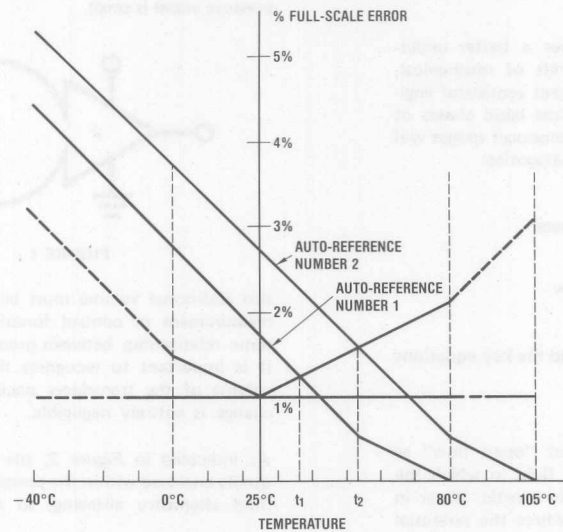


FIGURE 15. Figure 1 with Auto-Reference #1 and Auto-Reference #2 Curves Added

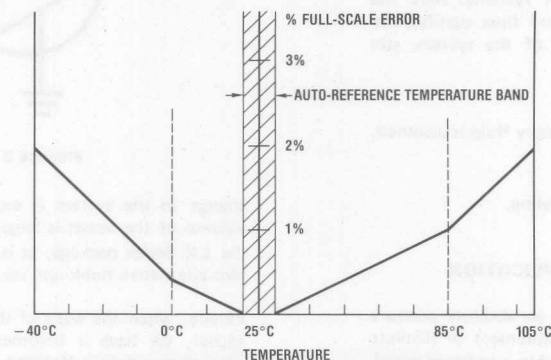


FIGURE 16. Limited Auto-Referencing

Transducers in Fluid Flow Applications

INTRODUCTION

People have been building fluid systems for many millenia and the knowledge of how to measure pressure in the fluids is centuries old. So what's so special about the line of transducers introduced by Sensym? In a nutshell, the solid state transducer allows much better sensing and, therefore, much better control of fluid systems for a given amount of money spent on system control.

To give the electrical engineer a better understanding of the strange worlds of mechanical, chemical, aeronautical, civil, and acoustical engineers we will describe the three basic classes of transducer applications. All transducer usages will fit into one of the following categories:

1. Pressure Vessel
2. Open Flow
3. Closed Flow

Each is thoroughly described and the key equations of each class are derived.

For a mental model think of "open flow" as represented by the flow of a fluid in which the main energy involved is simply kinetic. Water in an aqueduct or a long pipe where the potential energy at the dam up in the mountains or the compressive energy of the pump has long since been converted to the kinetic energy of the flowing stream.

For "closed flow," think of a compressor as used for example in refrigeration systems. Here the fluid density is changing and thus significantly contributing to the energy of the system, still primarily kinetic.

In a "pressure vessel" a stationary fluid is assumed.

Now on to the system modeling.

"PRESSURE VESSEL" APPLICATION

The simplest application of an absolute pressure transducer is the direct measurement of absolute pressure of a fluid at rest within a pressure vessel.

The concept of a pressure vessel is very general here ... it merely represents that container of

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fluid which keeps the fluid free of dynamics. Thus, using this broad view, on a calm day ... the world is a pressure vessel. Likewise, a vacuum chamber is a pressure vessel.

As indicated in *Figure 1*, the LX Series can be plumbed into the pressure vessel, thus adding its own package volume and that of the plumbing to the volume of the pressure vessel. Where the pressure vessel is small,

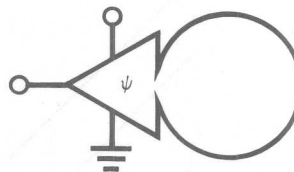


FIGURE 1

this additional volume must be considered if the measurement or control function involved seeks some relationship between pressure and volume.* It is important to recognize that the change in volume of the transducer package with pressure change is entirely negligible.

As indicated in *Figure 2*, the LX Series can be totally enclosed within the pressure vessel, working fluid chemistry allowing, so that little volume

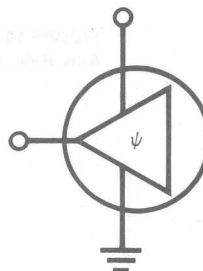


FIGURE 2

change in the system is experienced. When the volume of the vessel is large compared to that of the LX Series package, as is usually the case, the two alternative hook-ups are equivalent.

Finally, when the walls of the pressure vessel disappear, we have a barometer ... a very good application of the LX1602A.

*Care must be taken to avoid any temperature gradients between the pressure vessel and the transducer.

Pressure — Temperature Measurements

Another important family of "pressure vessel" applications for the LX-series involves the measurement of temperature used in conjunction with an absolute pressure reading. The integrated temperature sensing diode reads the temperature of the silicon diaphragm in the transducer package. This temperature signal may be used for the additional temperature compensation of the pressure signal.

The accuracy of the transducer depends primarily upon the temperature coefficients of the pressure signal. This is typically one to two orders of magnitude looser than the precision, which depends upon hysteresis and deadband. Therefore, for such devices, if one were to calibrate the pressure signal temperature error in terms of the temperature signal, then a correction table could be established to increase its accuracy to the same order as its precision.

Other Fluid Functions

By suitably combining the temperature with the pressure signal other fluid variables within the pressure vessel can be formulated. Two important fluid variables are density and heat content.

Density of a known gaseous fluid can be calculated without knowledge of the fluidic thermodynamic process going on simply by measuring simultaneously the pressure and temperature at the same point as described in equation 1.

Equation 1:

$$\rho = C_2 \frac{P}{T} ;$$

where

ρ = density

P = pressure

T = temperature

C_2 = inverse gas constant

Knowing the pressure, temperature and the density of the fluid at one or more points simultaneously, much can be learned about the nature of the processes causing change in the fluid. In a bounded pressure vessel, one variable often of concern is the heat transfer or energy exchange within some portion of a cycle or during some specific period. The change in heat content at a specific point in the system can be traced most easily in the bounded pressure vessel by tracking the fractional change in pressure as shown in equation 2.

Equation 2:

$$dh = C_3 \frac{P}{\rho} \left(\frac{d\rho}{P} \right) ;$$

where: dh = change in heat content

$$\left(\frac{d\rho}{P} \right) = \text{fractional change in pressure with time}$$

C_3 = inverse Joule's constant

If one were willing to track the fractional change of temperature and density as well as that of pressure, then complete knowledge of the state of the enclosed fluid as well as a complete characterization of the changing process results. Expressing equation 1 in terms of fractional changes yields equation 3.

Equation 3:

$$\left(\frac{d\rho}{P} \right) - \left(\frac{dT}{T} \right) = \left(\frac{d\rho}{\rho} \right) ;$$

where

$$\frac{dT}{T}, \frac{d\rho}{\rho} = \text{functional change of temperature and density with time}$$

Define a process characterization constant C_4 as shown in equation 4 and substitute in equation 3.

Equation 4:

$$C_4 \equiv \frac{\left(\frac{d\rho}{P} \right)}{\left(\frac{d\rho}{\rho} \right)} = 1 + \frac{\left(\frac{dT}{T} \right)}{\left(\frac{d\rho}{\rho} \right)}$$

Figure 3 is a table of this characterization constant under a number of important practical conditions.

So, by measuring absolute pressure changes and absolute temperature changes in an enclosed fluid system, one is able to characterize the process which caused the change of fluid properties. The process characterization constant (C_4) relates original oil changes in system energy to changes in fluid state defined by pressure, temperature, and density.

C_4	FLUID STATE	FLUID THERMODYNAMIC PROCESS	
0	$\left(\frac{dp}{P}\right) = 0$	$P = \text{constant}$	ISOBARIC
1	$\left(\frac{dT}{T}\right) = 0$	$T = \text{constant}$	ISOTHERMIC
$1 < n < k$	$\left(\frac{dp}{P}\right) = n \left(\frac{d\rho}{\rho}\right)$	$\frac{P}{\rho n} = \text{constant}$	POLYTROPIC (Adiabatic and Irreversible)
k	$\left(\frac{dp}{P}\right) = k \left(\frac{d\rho}{\rho}\right)$	$\frac{P}{\rho k} = \text{constant}$	ISENTROPIC (Adiabatic and Reversible)
∞	$\left(\frac{d\rho}{\rho}\right) = 0$	$\rho = \text{constant}$	INCOMPRESSIBLE (If bounded fluid gaseous, then process is ISENTHALPIC)

Note: In all cases dP , dT , $d\rho$ represent changes with time of the absolute values of P , T , and ρ .

FIGURE 3. State and Process Characterization

Phase Change

The process characterization constant poorly defines thermodynamic processes where changes of phase are involved. Where a phase change from gaseous to liquid fluid is involved, a characteristic energy transfer called latent heat (H_{LATENT}) occurs in accordance with expression given by Clapeyron, shown as equation 5.

Equation 5:

$$H_{\text{LATENT}} = \frac{T}{C_2} \cdot \frac{\left(\frac{dp}{P}\right)}{\left(\frac{dT}{T}\right)} ;$$

where

C_2 = inverse gas constant

For various fluids entering phase change, a new process characterization constant (C_5) given by Clausius/Clapeyron, shown in equation 6.

Equation 6:

$$C_5 = \text{LOG}_e P + \frac{C_2}{T} \cdot H_{\text{LATENT}}$$

$$\text{or } C_5 = \text{LOG}_e P + \frac{\left(\frac{dp}{P}\right)}{\left(\frac{dT}{T}\right)}$$

Thus, we have developed the equations of state for fluids undergoing thermodynamic processes with and without phase changes so as to characterize these processes via measurement of pressure and temperature within a pressure vessel using the absolute transducer.

Generally, measurements of pressure and temperature in a multiphase system are difficult. Often for the purpose of measurement, a small parallel tap is made into the main flow channel so as to divert a negligible portion of the fluid flowing; then a sudden expansion is performed in the tap, and a small tap is led back into the main flow channel. This type of device is called a flash chamber and is shown in Figure 4.

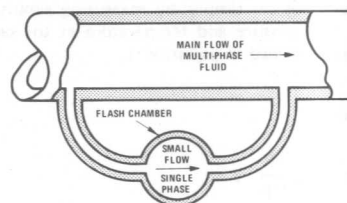


FIGURE 4

The flash chamber accomplishes the conversion of multiphase system (liquid and gas) to a single phase system (gas).

Such a chamber is simply a pressure vessel susceptible to analysis by the aforementioned modeling techniques.

OPEN FLOW APPLICATIONS

Just as pressure vessel processes were characterized by thermodynamic changes in fluid media rather than kinetic or spacial changes, open flow conditions and processes are best characterized as those in which we are primarily concerned with the kinetic properties of a fluid system and their changes, rather than the state and changes of state of a controlled volume of fluid. Whereas in the pressure vessel measurements involve absolute pressure, the kinetic state of an open flow system most often requires gage and differential pressure transducers.

The form of Bernoulli's flow equations most applicable to open flow conditions is given in equation 7.

Equation 7:

$$\left(\frac{P}{\rho}\right)_{\text{STAGNATION}} = \left(\frac{P}{\rho}\right)_{\text{STATIC}} + \frac{V^2}{2g} + y;$$

where:

$$\left(\frac{P}{\rho}\right)_{\text{STAGNATION}} = \text{Stagnation pressure head}$$

$$\left(\frac{P}{\rho}\right)_{\text{STATIC}} = \text{Static pressure head}$$

$$\left(\frac{V^2}{2g}\right) = \text{Kinetic flow head}$$

$$y = \text{Potential flow head}$$

This particular form of Bernoulli's equation is valid where fluid density remains reasonably constant. As seen in the definition of terms (equation 7), the concept of a head is key to open flow applications. Easiest to conceive is the potential head, wherein a particle of fluid at a different height than at some other location has some potential to flow to that other location. That potential is proportional to the height difference. It is small wonder, therefore, that dimensions of a head are those of a column of fluid; inches of mercury, feet of water, millimeters of mercury or torr. If that particle of fluid were to fall, so as to change location or flow, without changing pressure within that particle, then that potential flow head would convert to a kinetic flow head. Another useful concept in equation 7 is that of stagnation. If you were waiting with a catcher's mit at a fixed location and a particle of fluid at a given pressure flowed into the mit, in order to stop that particle with your mit you would have to bring it to rest. In doing so, assuming the fluid particle remained at the same density and temperature, the particle's pressure head would increase by the absorbed kinetic head. If you were then to pull the mit down to ground level, the stagnation head would in addition increase by the potential head. Therefore, the stagnation head of a given fluid particle is an expression of that particle's pressure were it suddenly brought to rest and dragged to the bottom. Bernoulli's equation indicates that however that particle may meander under open flow conditions, the sum of its static pressure head, its kinetic flow head, and its potential flow head remains constant. In most open flow situations the variable of major interest

is flow velocity. In situations where it is convenient to measure both stagnation pressure and static pressure at essentially the same point (y is constant) a differential pressure transducer can be used in a method similar to that of a pitot-tube as shown in *Figure 5*. Equation 7 can then be rearranged as shown in equation 8.

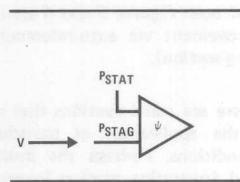


FIGURE 5. Flow Rate Pressure Square Law Relationship

Equation 8:

$$V_y = \sqrt{2g \left[\left(\frac{P}{\rho}\right)_{\text{STAGNATION}} - \left(\frac{P}{\rho}\right)_{\text{STATIC}} \right]}$$

Applications where this type of measurement is common are air speed indication for airplanes and weather balloons, water speed for boats and aqueducts and irrigation ditches, ventilation control, sewage processing, industrial mixing, and others. More generally, where y varies in open flow conditions, changes in flow conditions due to geometric changes in the flow boundaries are monitored by measurements of fluid level changes and fluid pressure changes. Equation 9 gives the applicable form of Bernoulli's equation.

Equation 9:

$$\frac{dv}{g} + \frac{dp}{\rho} + dy = 0,$$

where dv , dp , dy are changes with distance

Figure 6 shows this general case of open flow boundary condition monitoring. Notice that both the fluid level and each of the gage transducers used are vented to atmosphere for reference. In this particular case, the use of a differential

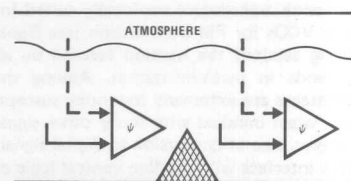


FIGURE 6. Flowmeter Output with Exaggerated Pressure Transducer Common-Mode Inaccuracy

transducer is not practical due to the physical separation of the points of interest. Two transducers must be used. Examples of applications include weir and dam flow and level control, oceanographic measurements, and for the special cases of near zero velocities ... general level control.

The schemes of both *Figures 5 and 6* are ideal for accuracy improvement via auto-referencing (see auto-referencing section).

Once again there are some cautions that must be respected in the application of transducers in open flow conditions. Perhaps the most often overlooked and frustrating caution involves temperature gradient. As was explained in the pressure vessel section, although good transducers are temperature compensated, temperature gradients within the transducer are deadly enemies producing errors that defy all compensation techniques. If the temperature signal from the LX Series transducers is used in determining the density of the working fluid, then the transducer wants to be thermally well-coupled. However, if the atmospheric environmental temperature is significantly different from that of the working fluid, a severe gradient of temperature can occur within the transducer unless the transducer is totally immersed in the working fluid (a condition usually impractical). Fortunately, in most open flow applications, the temperature reading is not needed to determine density and the dynamics of the flow do not prohibit fairly long tube lengths from the transducer to the point of measurement. The result is that it is practical to provide a situation wherein the working fluid within the transducer is at the same temperature as the surrounding environment.

One extremely useful feature of the LX Series pressure transducers comes into play in applications of the type shown in *Figure 6*. In many such open flow applications the distance between points one and two is measured in miles. In such cases the system accuracy is not simply dependent upon the accuracies of measurements of pressure point one and point two but rather the difference calculation Δp . Obviously that accuracy depends on the transmission of information over several miles. In general, maintaining accuracies under these conditions requires healthy signal to noise ratio at each transducer output as well as a hefty pre-transmission signal and easy interface with the transmitter.

The IC pressure transducers are ideally suited for coupling to VCOs for FM transmission (see Signal Conditioning section) the method favored by all modern trends in instrumentation. Among the many advantages are extremely low noise susceptibility even when bundled with many other signal carrying cables, ease of conversion to digital signals to facilitate interface with modern control logic or input to general purpose digital computers, and ease of combination with other analog FM signals to form a composite system variable.

ACOUSTICS

One special form of open flow application is the case where the pressure wave velocity is high compared to the fluid flow velocity. Such applications are called acoustic. The acoustic energy of a sound wave is directly proportional to the sound pressure as shown in equation 10.

Equation 10:

$$\Delta h = C_3 \frac{\Delta p}{\rho}$$

For acoustics, the open flow approximation of an "incompressible, isothermic medium" must be replaced by the model of a "stationary, isentropic medium." That is, the propagating pressure wave shakes each fluid particle about its stationary location proportional to the sound pressure constituting a dynamic change in density ($\Delta \rho$). As shown in equation 11, the proportionality constant between the change in the fluid density and the sound pressure is the inverse squared speed of sound in that medium.

Equation 11:

$$\Delta \rho = C_7 \Delta p; C_7 = \frac{1}{a^2};$$

where "a" is the speed of sound.

Sound pressure measurements should be made with differential transducers in which the reference point monitors the quiescent pressure level. sound pressures are very low, so as to require the LX1601G or LX06001G.

High frequency response can be severely limited by bounded chambers. In fact just the tube and lid can limit response normally in the tens of kilo Hertz to the low kilo Hertz region. However, the silicon pressure diaphragm response alone with the tube and lid removed or when liquid coupled is such that calibrated sound pressure measurements can be achieved at frequencies well above 50 kilo Hertz. Thus, the LX Series pressure transducers are capable of calibrated pressure measurements in open flow conditions ranging in dynamics from static to ultrasonic frequency.

CLOSED FLOW APPLICATIONS

Pressure vessel applications require the investigation of time dependent variables at one point. Open flow applications require the investigation of time independent variables at many points. In

closed flow applications, we need to investigate both kinds of variables. That is, the processes at work within the fluid system involve state change energies of like order of magnitude as kinetic energies. Perhaps the most obvious examples of systems reliant on such processes are engines of all kinds, as well as refrigerators and air conditioners, compressors, gas pipelines, fire extinguishers, gun cartridges and explosives.

In closed flow the equation used to model the flow between two locations must be altered to include the change of state.

Equation 12:

$$h_{\text{STAGNATION}} - h = C_3 \left[\frac{P}{\rho} \right]_{\text{STAGNATION}} - \frac{P}{\rho} = C_3 \left(\gamma + \frac{V^2}{2g} \right)$$

In equation 12, $h_{\text{STAGNATION}}$ represents the total equivalent heat energy of the system and is constant; h is the heat content of a fluid particle at a particular location such that $(h_{\text{STAG}} - h)$ represents the kinetic and potential flow energy.

In open flow the density of the fluid is assumed to be known and constant. Consider a working fluid that is gaseous and whose density variation may be described by equation 1 of the pressure vessel applications section. Equation 13 shows the substitution of equation 1 in equation 12.

Equation 13:

$$h_{\text{STAGNATION}} - h = \left(\frac{C_3}{C_2} \right) T \left[\frac{P_{\text{STAGNATION}}}{P} - 1 \right] = C_3 \left(\gamma + \frac{V^2}{2g} \right)$$

In the same manner in which equation 8 was derived from equation 7 in the section on open flow applications, equation 14 is derived from equation 13 to show flow velocity.

Equation 14:

$$V_y = \sqrt{2g \left[\frac{T}{C_2} \left(\frac{P_{\text{STAGNATION}}}{P} - 1 \right) \right]}$$

Thus, where the system allows a Pitot tube measurement of the two absolute pressures and temperatures at one point, the closed flow can be modeled by equation 14 and two LX Series transducers. Common applications include high velocity air flow as in compressors, and engine manifold gas flow.

To measure closed flow in small flow channels, it is usual to insert an obstruction in the passage between two points at which fluid properties can be sensed. Again, rather than the incompressible and isothermic conditions applicable to liquids in open flow, heat transfer and in fact heat loss due to flow conditions is experienced. Equation 15 presents Bernoulli's equation for this situation with the energy loss due to obstruction indicated in terms of change in heat content. For extremely long, thin, rough-walled, closed-flow vessels, the fractional loss can actually approach unity.

Equation 15:

$$\left[\frac{\gamma_2 + \frac{V_2^2}{2g}}{\gamma_1 + \frac{V_1^2}{2g}} \right] = 1 - \left(\frac{h_1 - h_2}{h_{\text{STAGNATION}} - h_1} \right);$$

where

$$\left(\frac{h_1 - h_2}{h_{\text{STAGNATION}} - h_1} \right) = \text{Loss of energy}$$

Structures are used that tend to minimize the distance between sensing points as well as minimize the fractional loss of energy. Commonly used structures range from orifices where losses are up to half of the total energy and sensing points are very closely spaced, to Venturi's where losses are negligible but sensing points are widely spaced. Equation 16, derived from equation 15 shows a typical calibration equation for a specific obstruction over a specific range of flow.

Equation 16:

$$\left(\frac{V_2}{V_1} \right)_y = \sqrt{1 - \left(\frac{h_1 - h_2}{h_{\text{STAGNATION}} - h_1} \right)}$$

Figure 7 shows some typical flow measurement obstructions.

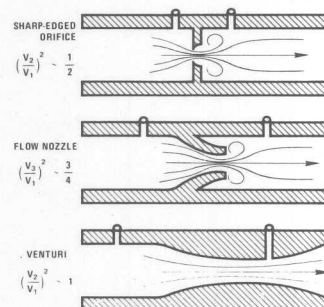


FIGURE 7

It must be remembered that these are rule of thumb examples and fluids undergoing drastic thermodynamic changes will not approximate these

processes for these flow conditions. For example, the nearly lossless Venturi of streamlined flow conditions forms a roaring energy loser when turbulent hot gases are pushed through so as to become the converging-diverging nozzle of rocketry fame.

OPEN VS CLOSED FLOW

Conventionally, differential pressure transducers rather than absolute transducers are used for flow measurement. Three arguments are popular for maintaining this convention . . . one of them very good and the other two rather weak.

In low flow rate applications the dynamic head is most often small compared to the static head. The incompressible isothermic model, expressed in the equations of the open flow applications section, is often appropriate under such low flow conditions. The resulting simple expression of Bernoulli's equation that leads to the use of differential pressure transducer is given by equation 17.

Equation 17:

$$d(V^2) = C_8 \left(\frac{dp}{\rho} \right); \rho \neq \rho(p, t)$$

In addition to being the analytically obvious best choice when equation 17 is an appropriate model of flow conditions, a single differential transducer can be made to perform with much greater accuracy than a pair of gage or absolute transducers of comparable quality because the differential transducer need only range both the dynamic and static heads. Since the static head is not called for in equation 17, the added ranging requirement merely adds common mode error to the measurement. Under these conditions the differential pressure transducer convention for flow measure-

ment is justified and the differential transducers are highly recommended . . . particularly with auto-referencing.

Equation 18:

$$d(V^2) = C_9 d\left(\frac{p}{\rho}\right); \rho = \rho(p, t)$$

Traditionally, even in cases where more complex Bernoulli models (equation 18) should be used, the simple incompressible model is substituted. One argument claims that one can always make up for errors in the modeling equation by specifying greater accuracy in the differential pressure transducer. Proponents of this argument consider the alternate use of two absolute pressure transducers along with two temperature transducers (to achieve a more accurate modeling equation) too sophisticated. The tradition of simple single variable models using few highly accurate transducers to achieve moderate system accuracy is so well founded in the measurement and control industries that until recently only manufacturers of low volume, high accuracy, high cost transducers existed. The low cost LX Series devices are first and foremost integrated circuits (that happen to be transducers as well) rather than conventional transducers (that happen to utilize integrated circuits). In electronics in general, and specifically within the integrated circuits business, adding functions is easy . . . but measuring to a tight spec is difficult.

In most closed flow applications the variables of interest are functions of absolute pressure, differential pressure, and temperature, with respect to time and location. If the system modeler desires a certain tolerance on this complex function he may either gather single variable data at multiple locations or multivariable data at few locations.

In either case, auto-referencing techniques can greatly improve system accuracy.

Flow Velocity Measurement— Example of Analog Shaping Conditioning

SenSym SSAN-11

The pressure developed by a flowing fluid is a direct function of the square of the flow velocity. Therefore, to use an LX series pressure transducer for the determination of a fluid's flow velocity it is necessary to extract the square root of the transducer's analog voltage output: $V_T = f(P_{IN})$; $P_{IN} = f(v^2)$; so, $(V_T)^{1/2} = f(v)$.

One way to accomplish square rooting is to make use of the logarithmic relationship that exists between the voltage drop across a diode junction and the current through it. We can use a diode's voltage/current relationship because, over a limited range of values, the ratio of the natural log of a number to its square root is approximately constant. Table I shows this relationship in terms of values of N that are numerically equal to the 2.5V to 12.5V output voltage span of Sensym's LX series of pressure transducers.

TABLE I

N	$N^{1/2}/\ln(N)$	$1.37 \times \ln(N)$ (Const. Mult.)	% Deviation From True $N^{1/2}$
2.5	1.73	1.26	-20.6
3	1.58	1.51	-13.0
4	1.44	1.90	-5.00
5	1.39	2.20	-1.43
6	1.37	2.46	+0.24
7	1.36	2.67	+0.76
8	1.36	2.85	+0.71
9	1.37	3.01	+0.33
10	1.37	3.16	-0.22
11	1.38	3.29	-0.96
12	1.39	3.40	-1.73
12.5	1.40	3.46	-2.12

The implementation of the concept, however, is a bit more complex than simply forcing a current through a diode, measuring the junction voltage drop and scaling it in an amplifier. But an amplifier that works on that principle and does the job is shown in Figure 1; it uses a

pair of matched, diode-connected transistors as the logarithmic elements. The transfer function of the circuit is complex, but the output voltage variation is of the form $V_{OUT} = A \ln(V_T/B)$, where A and B are constants.

Figure 2 shows the amplifier's performance in terms of the deviation of the output voltage (V_{OUT}) from a true square root of the input voltage ($V_T^{1/2}$). Varying the value of the resistor, R, shifts the curve along the percentage axis. This value may be set as required to suit any particular application.

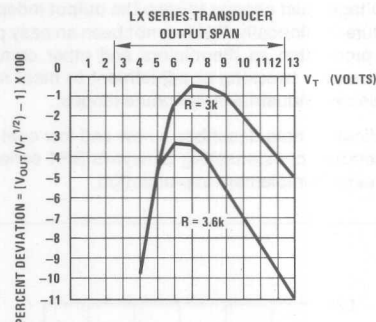


FIGURE 2. Square-Rooting Error Performance of the Amplifier

Better curve fitting can be achieved by using an LH0094 in place of the circuit of Figure 1.

Greater accuracy can be achieved using the dual slope integration technique described later in this section.

Still greater accuracy can be achieved using the flexural iris approach described in Section 6.

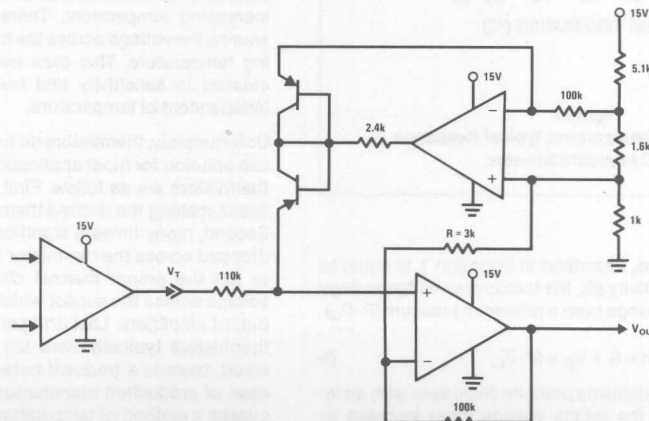


FIGURE 1. Square-Rooting Amplifier for Flow Velocity Measurements

IC Sensor Signal Conditioning

Programmable Current Source Provides Novel Method of Span Compensation

by Roland Lee

INTRODUCTION

Ideally, an IC pressure sensor's output should be independent of temperature. Unfortunately, for all IC pressure sensors, as the ambient temperature is increased, the sensitivity actually decreases. In simple terms, it acts as though the diaphragm in the IC sensor actually gets stiffer with increases in temperature. Therefore, the sensitivity of the diaphragm to pressure actually decreases with increases in temperature. (See Figure I.) To compensate for these changes in sensitivity, the sensor's bridge voltage must change to keep the output independent of temperature. Historically, this has not been an easy problem to solve in production as thermistors and other compensation schemes require tweaking or adjustment to meet reasonable tolerances over industrial temperature ranges.

This application note describes a new and low cost approach for temperature compensating Sensym's SPX series sensors which is easy to implement in production.

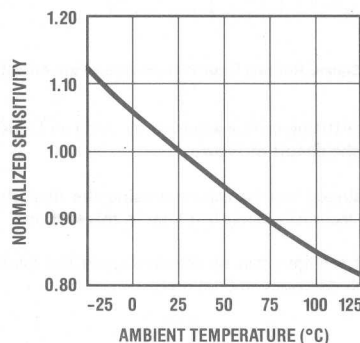


Figure I
Sensitivity vs. Temperature, Typical Response
for IC Pressure Sensors

THE PROBLEM

The sensor's actual span, described in Equation 1, is equal to the product of the sensitivity (S), the transducer bridge voltage (V_B) and the pressure change from a reference pressure ($P-P_0$).

$$\text{Span} = S \cdot V_B \cdot (P - P_0) \quad (1)$$

However, because the sensitivity actually decreases with an increase in temperature, the bridge voltage must increase or change in the opposite direction in order for the output voltage span to remain independent of temperature.

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THE OLD SOLUTION-THERMISTORS

One of the older and more common methods of providing span compensation for pressure sensors involves the use of thermistors as shown below in Figure II.

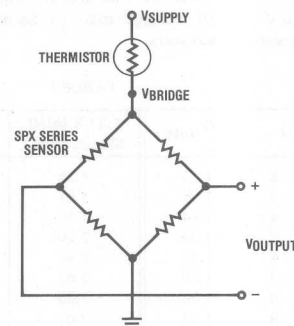


Figure II
Simple Thermistor Compensation Scheme

The basic idea behind the various thermistor compensation schemes is that the resistance of the thermistor decreases with increasing temperature. Therefore, with a constant voltage source, the voltage across the bridge will increase with increasing temperature. This then compensates the sensor for decreases in sensitivity and keeps the overall sensor output independent of temperature.

Unfortunately, thermistors do not provide a simple and easy-to-use solution for most applications. Some of the problems with thermistors are as follow. First, low cost thermistors are non-linear, making the desired thermal response difficult to obtain. Second, many times a significant amount of voltage must be dropped across the thermistor compensation network in order to get the proper thermal characteristics. This leaves less voltage across the sensor which necessitates more gain in the output amplifiers. Last and perhaps most important, low cost thermistors typically have ten percent tolerances and, as a result, there is a trade-off between thermistor error, cost, and ease of production manufacturing. The following section discusses a method of temperature compensating Sensym's sensors using low cost, close tolerance IC devices such as the LM334 to eliminate these problems.

THE NEW SOLUTION

General Discussion

By using an LM334, one can compensate an IC sensor easily and inexpensively. The LM334 is a three-pin programmable current source featuring an output current that rises linearly with temperature at $+0.336\%/^{\circ}\text{C}$. (See the LM334 data sheet from National Semiconductor Corp.) Taking the typical temperature coefficients from the SPX series data sheet, one can see that putting the LM334 directly in series with the SPX devices would result in overcompensating for the sensor's changes in sensitivity over temperature. This is due to the fact that the bridge sensitivity changes at $-2350\text{ppm}/^{\circ}\text{C}$ while the LM334 and changing resistance of the sensor would combine to cause the voltage across the sensor to change at $+4710\text{ppm}/^{\circ}\text{C}$. The circuit shown in Figure III allows one to adjust resistor R_2 to reduce the overall TC of the compensation circuitry to provide span compensation of $+2350\text{ppm}/^{\circ}\text{C}$, which compensates for the drop in bridge sensitivity.

This method of span compensation also allows the bridge voltage to be selected and not determined by the voltage across the compensation network. The main advantage of this is that one can select the bridge voltage to be as high as 1V below the supply voltage. This higher voltage across the bridge minimizes gain needed in later amplifier networks.

Span errors of less than 1% can be obtained between 0°C and 75°C by using this circuit. One should note, however, that beyond this 0°C to 75°C temperature range thermistors or more complex compensation schemes will be needed to again achieve errors on the order of 1%.

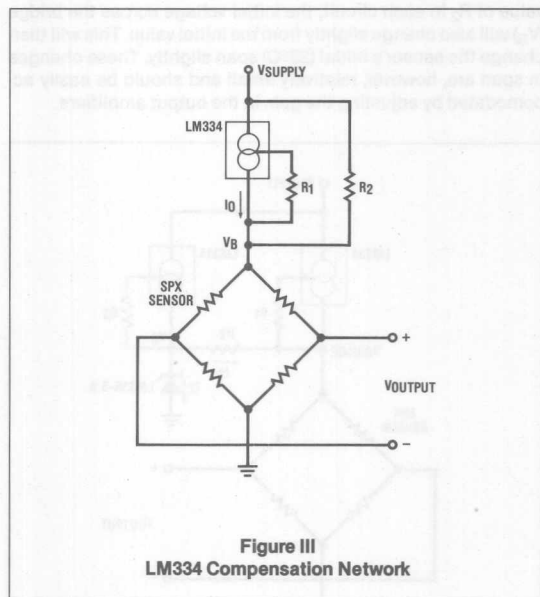


Figure III
LM334 Compensation Network

Calculations:

In order to obtain the desired span compensation, the best resistor values of R_1 and R_2 must be calculated. By solving the nodal equation for the bridge voltage, the bridge voltage equation becomes:

$$V_B = \alpha [V_S + I_O R_2] \quad (2)$$

Now taking the derivative with respect to temperature and normalizing it with respect to the bridge voltage at 25°C , we obtain:

$$\frac{\dot{V}_B}{V_B} = \frac{I_O}{I_O} \left(1 - \alpha \frac{V_S}{V_B} \right) + \frac{\dot{R}_B}{R_B} (1 - \alpha) \quad (3)$$

Where:

$\frac{\dot{V}_B}{V_B}$ = The temperature coefficient of the bridge voltage ($\text{ppm}/^{\circ}\text{C}$)

$\frac{I_O}{I_O}$ = The temperature coefficient of the LM334 current source ($\text{ppm}/^{\circ}\text{C}$)

V_S = Supply voltage (Volts)

V_B = The desired initial bridge voltage at 25°C (Volts)

$\frac{\dot{R}_B}{R_B}$ = The temperature coefficient of the bridge resistance ($\text{ppm}/^{\circ}\text{C}$)

R_B = The initial bridge resistance @ 25°C (Ω)

$$\alpha = \frac{R_B}{R_2 + R_B}$$

Solving this equation for resistor R_2 :

$$R_2 = \frac{R_B \left[\frac{I_O}{I_O} \left(\frac{V_S}{V_B} - 1 \right) + \frac{\dot{V}_B}{V_B} \right]}{\frac{\dot{R}_B}{R_B} + \frac{I_O}{I_O} - \frac{\dot{V}_B}{V_B}} \quad (4)$$

Once R_2 is known, R_1 can be derived from the equation:

$$R_1 = 67.7 \text{ mV} \frac{(R_2 \alpha)}{V_B - \alpha V_S} \quad (5)$$

$$\text{and } I_O = \frac{67.7 \text{ mV}}{R_1} \quad (\text{See LM334 datasheet})$$

EXAMPLE:

Consider the following example:

Assume that the voltage supply is 5V with an initial bridge voltage of 3V. From the SPX data sheet, we have the following:

$$R_B = 500 \Omega$$

$$\frac{I_O}{I_O} = 3360 \text{ ppm}/^{\circ}\text{C}$$

$$V_S = 5 \text{ V}$$

$$V_B = 3 \text{ V}$$

$$\frac{\dot{V}_B}{V_B} = +2350 \text{ ppm}/^{\circ}\text{C}$$

$$\frac{\dot{R}_B}{R_B} = +1350 \text{ ppm}/^{\circ}\text{C}$$

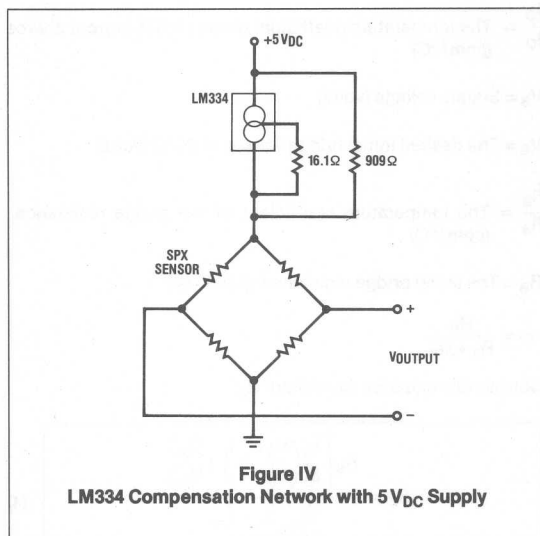
Substituting the above values into equations 4 and 5 we find that:

$$R_2 = 914 \Omega \text{ and}$$

$$R_1 = 16.1 \Omega.$$

The closest standard value 1% resistors are $R_2 = 909 \Omega$ and $R_1 = 16.1 \Omega$.

The circuit using a 5V supply and these resistor values is then shown below:



Calculated resistor values for other supply voltages are shown in the table below:

TABLE 1. Calculated R Values vs. V_S

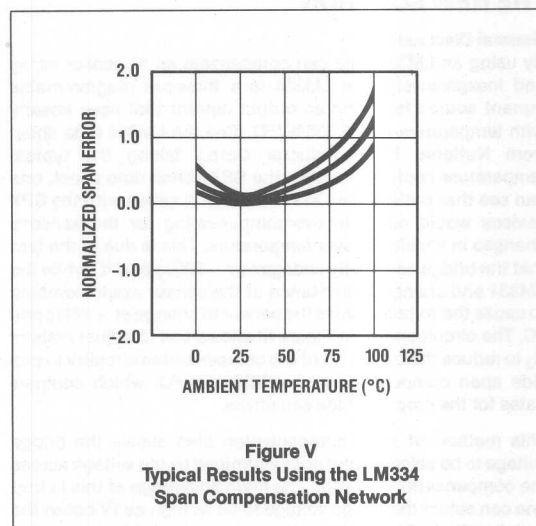
V _S	R ₁ (Ω)	R ₂ (Ω)
5V _{DC}	16.1	914
9V _{DC}	23.5	1922
12V _{DC}	26.2	2633

$$V_B @ 25^\circ\text{C} = 3.0\text{V}_{\text{DC}}$$

Typical Circuit Performance

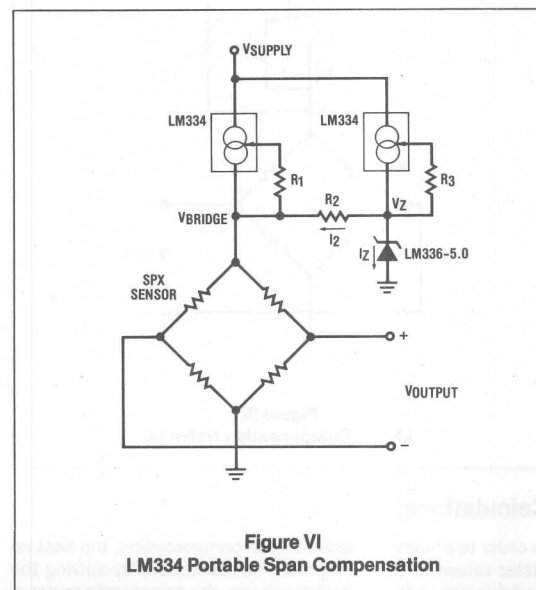
Using the values calculated above for R_1 and R_2 , several devices were measured over temperature with the results of these devices shown in Figure V. Typical errors were found to be in the range of $\pm 1\%$.

If the fixed resistor values shown in Figure IV are used in volume manufacturing, the worst case span error of a single device that can be expected over a 50°C temperature range is $+2.9\%$ to -3.6% . This is computed using the maximum and minimum limits from the SPX data sheet for R_B , $\bar{R}_B$ and TC span. This is a



worst case calculation and it would be extremely improbable that all errors would accumulate in the worst case direction.

If higher accuracy is desired, resistor R_2 can be replaced with a 768Ω 1% metal-film resistor in series with a 300Ω metal-film potentiometer. Each system can then be individually adjusted to be within acceptable limits. When using a pot and adjusting the value of R_2 in each circuit, the initial voltage across the bridge (V_B) will also change slightly from the initial value. This will then change the sensor's initial (25°C) span slightly. These changes in span are, however, relatively small and should be easily accommodated by adjusting the gain in the output amplifiers.



BATTERY OPERATION

For battery operation, the circuit shown in Figure VI is recommended. By using a second LM334, the current, I_2 , will not change with the battery voltage. An LM336-5.0 is used to isolate the resistor R_2 from the battery voltage. Equations 4 and 5 can be used to find R_1 and R_2 with V_S replaced by V_Z (5V in this example).

To find R_3 , we need to find the current through R_2 , which is given by:

$$I_2 = \left(\frac{1}{R_2} \right) (V_Z - V_B)$$

Then R_3 should be selected to give I_2 plus an additional I_Z for the zener diode. Therefore:

$$R_3 = \frac{67.7 \text{ mV}}{I_2 + I_Z}$$

Notice I_2 will change with temperature but the voltage V_Z will not.

Typical values for operation using a 9V battery and 3V across the bridge would be:

$$I_2 = 1 \text{ mA}$$

$$R_1 = 16.1 \Omega \text{ } 1\%$$

$$R_2 = 909 \Omega \text{ } 1\%$$

$$R_3 = 19.6 \Omega \text{ } 1\%$$

This circuit will operate until the battery voltage drops below $V_S = 6.0 \text{ V}$.

CONCLUSION

By using the LM334 and two metal-film resistors, span compensation of IC sensors can be accomplished easily and accurately. The span compensation error will typically be less than 1% from 0°C to 75°C. This technique is conducive to volume manufacturing, as it does not involve non-linear elements such as thermistors. Additionally, the method is suitable for portable and battery applications since the voltage across the bridge can be made independent of the supply (battery) voltage.

Sensor Signal Conditioning

Using the LX06XXX Sensors with a Single Supply

Sensym Application Dept.

Sensym
SSAN-17

INTRODUCTION

The LX06XXX series of sensors provide a very cost effective method to measure pressures in the full scale range from 1 psi to 100 psi. The LX06XXX series incorporates integral thick film passive networks to compensate the bridge for span, span temperature effects, and offset voltage. With preset factory compensation of the above parameters, the LX06XXX family becomes a very cost effective component to use by simply adding gain to the sensor's output.

This application note discusses the design of a low cost, but high performance amplifier which can be used with the LX06XXX devices when it is desirable, or necessary, to operate the device from a single supply voltage.

The amplifier discussed will operate equally well over a supply range from +5 volts to +15 volts and provides an output voltage that will swing within millivolts of the power supply and ground. The design makes use of a minimum number of components and is easy to produce in volume manufacturing due to the fact that the adjustments that are required, are totally non-interactive. An example is given for the design of a tension control system for a magnetic tape air bearing.

AMPLIFIER DESIGN

The output of the sensor is given by the following equation:

$$V = SV_S P \pm V_{OS} \quad (1)$$

where: V is the differential output voltage of the bridge in mV.
 S is the sensitivity in mV/V per PSI.
 V_S is the voltage applied to the top of the bridge.
 P is the applied pressure in PSI.
 V_{OS} is the differential output voltage (error) that is present when the applied pressure is zero.

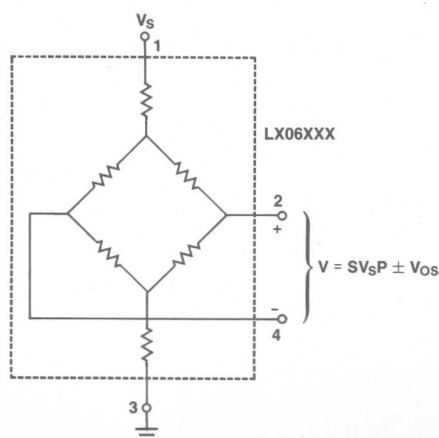


FIGURE 1

The first term on the right side of the equation, $SV_S P$, is known as the SPAN. From the LX06XXX data sheet, the span will be found to be in the range of 28mV (for LX06001) to 140mV (for the LX06100), and the offset voltage, V_{OS} , ranges from ± 1 mV to ± 2 mV, when operated from a bridge supply voltage of 10.0 volts. Since the span and offset voltage are both ratiometric to the supply voltage, these parameters can be easily calculated for supply voltages other than 10 volts. For example, for V_S equal to 5.0 volts, the span and the offset should be one-half of the data sheet guaranteed parameters.

Because the output voltage, given in Equation 1, is a differential output, the amplifier must perform the function of converting the differential output to a single-ended output referred to ground. Secondly, the design must provide a method of eliminating the V_{OS} term, so that the voltage at the output of the amplifier does not contain this error term. Thirdly, since the common-mode voltage appearing at the arms of each output is approximately one half of V_S , the amplifier should not provide gain to this common-mode voltage. That is to say, the amplifier circuit should have very high common-mode rejection. The amplifier should not load the bridge, which would cause additional errors, and of course the amplifier circuit should amplify the signal to provide the desired output voltage. Finally, all adjustments necessary to provide the above functions should be non-interactive. The circuit shown in Figure 2 meets all of these requirements.

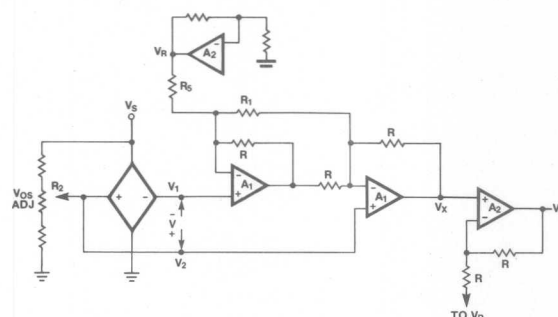


FIGURE 2

Neglecting the small error terms of the op amps, the equation for the first stage output voltage, V_x , in terms of the bridge arm voltages, V_1 , and V_2 , is given by

$$V_x = V_2 \left[2 + \frac{2R}{R_1} \right] - V_1 \left[\left(1 + \frac{R}{R_5} \right) + \frac{2R}{R_1} \right] + V_R \left[\frac{R}{R_5} \right] \quad (2)$$

Now, consider this equation if there is no offset voltage from the bridge and no pressure applied. Then $V_1 = V_2 = V_{cm}$, where V_{cm} is the common-mode voltage. Substituting this into Equation 2 we have,

$$V_x = V_{cm} \left[1 - \frac{R}{R_5} \right] + V_R \left[\frac{R}{R_5} \right] \quad (3)$$

Since it is required that there be zero voltage gain to the common-mode voltage, we can adjust R_5 to be equal to R . When this is accomplished, Equation 2 becomes

$$V_X = (V_2 - V_1) \left[2 \left(1 + \frac{R}{R_1} \right) \right] + V_R$$

or,

$$V_X = V A_V + V_R \quad (4)$$

where A_V is the voltage gain, given by

$$A_V = 2 \left[1 + \frac{R}{R_1} \right] \quad (5)$$

and V is the differential input voltage (output of the bridge) given in Equation 1.

It should be noted that since resistor R_5 does not appear in the equation for A_V , once the common-mode rejection adjustment is made, the gain adjustment and common-mode rejection adjustment are non-interactive. From Equation 5, it can be seen that the gain can be easily set by adjusting R_1 .

The offset error, V_{OS} , can be adjusted to zero by adjusting R_2 (see Figure 2), so the expression for the input voltage is simply

$$V = S V_S P \quad (6)$$

From Equation 4, when there is zero pressure applied, the output voltage will be equal to V_R , which is simply any convenient reference voltage that is desired to denote zero pressure. V_R could be at ground potential, however this would require that the output of op amp A_1 be capable of swinging clear to ground while operating from ground. The output swing of some amplifiers can get close to ground if there is zero load current required, but in the real world, not even CMOS amplifiers will truly swing to ground. Establishing a positive voltage to represent zero pressure also eliminates the problem of "Do I have zero pressure or do I have a short?"

The output stage (Amplifier A_2) provides a non-inverting gain of 2 to signal V_X and a gain of minus one to the reference voltage V_R . That is,

$$V_0 = 2V_X - V_R \quad (7)$$

Using V_X from Equation 4, and substituting into Equation (7) we arrive at the final overall equation

$$V_0 = V \left[4 \left(1 + \frac{R}{R_1} \right) \right] + V_R \quad (8)$$

An output stage buffer has been incorporated to minimize any loading effects that could feed back to the main gain storage and to make use of the output swing capability of the LM10, which is used for A_2 and can swing very close to either supply rail.

The output swing capability of amplifier A_1 , (LT1013) is to within 1 volt of the positive supply and to within 50mV of ground. By incorporating the buffer stage with a gain of 2, the output swing at V_0 is to within 100mV of ground and to within 100mV of the positive supply.

DESIGN EXAMPLE

Consider the following design:

For a tape motion control system, an air bearing is used which measures a full scale differential air pressure of two PSI. It is desired that the output voltage be from 1 volt to 6 volts while operating from a regulated +12 volt system supply.

Selecting the LX06002D, the design steps are as follows:

1. Determine the output span of the sensor. From the LX06002D data sheet it is found that the output span with a 10 volt supply is $40 \text{ mV} \pm 1.5 \text{ mV}$. Therefore, with a 12 volt supply, the expected span will be $48 \text{ mV} \pm 1.8 \text{ mV}$.

2. Determine the total gain required. Since the amplified output span is 5 volts (from 1 volt to 6 volts), it is found that the required gain range is $100 \leq A_V \leq 110$. For $R = 100\text{K}$, the range of R_1 can be found to be from 3.63K to 4.17K. To provide a smooth adjustment, using a 15 turn metal film or cermet pot, select R_1 to be a 3.32K resistor in series with a 1K pot.

The final design, with circuit values, is shown in Figure 3. Although this design is for a single +12 volt supply, the circuit is capable of operating with a single supply from 5 volts to 15 volts with a total quiescent current drain of less than 5 mA over this supply range. Also, because there are seven 100K resistors, (denoted as R_A) a resistor array has been used. This provides excellent matching and tracking with temperature, as well as minimal cost and PC board space.

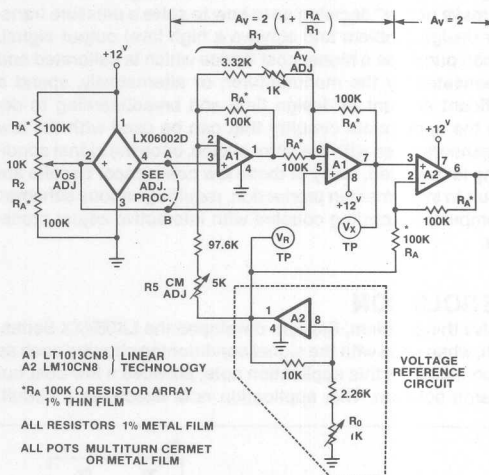


FIGURE 3

ADJUSTMENT PROCEDURE

1. Without pressure applied:
 - (a) Short the bridge arms together at points A and B shown in Figure 3. Adjust R_5 , the common-mode rejection pot, until V_X , the voltage at pin 3 of A_2 , is equal to V_R , the voltage at pin 1 of A_2 . This is easily accomplished by placing a digital volt meter between these pins and adjusting for 0.000V. The reasoning behind this is found in Equation 3.
 - (b) Remove the short, and adjust R_2 , the offset adjust pot, until V_X is again equal to V_R .
 - (c) Adjust R_0 , the reference adjust pot, to get an output voltage, V_0 , equal to 1.00V.
2. Apply the full scale pressure of 2 PSI. Adjust R_1 , the gain adjust pot, until the output, V_0 , is 6.00 volts.

CONCLUSION

The LX06XXX family of pressure sensors is extremely popular due to the fact that they are pre-trimmed for span, span TC and offset voltage. They offer a very economical method to sense pressures from 1 PSI to 100 PSI. Because many industrial systems have only one power supply available, this application note discusses a circuit which provides excellent performance, easy adjustment, requires little power, minimal PC board space, and is low cost.

Low Cost Precision Amplifier for the LX06XXX Series

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INTRODUCTION

With the advent of silicon IC pressure sensors, many low cost sensors have become available. One of the major problems with most low cost sensors available today is they have a low level uncalibrated output, and this output is uncompensated for changes in temperature. This leaves the designer with a difficult "make or buy" decision as to how to solve a pressure transducer design problem and achieve a high level output signal. One can purchase a higher cost device which is calibrated and compensated by the manufacturer; or alternatively, spend a significant amount of design time and breadboarding to develop the appropriate circuitry that can be used with the low cost sensors. Even with the latter choice, once the signal conditioning is designed, many of these low cost sensor circuits are difficult to implement in production, requiring various schemes for temperature cycling coupled with interactive adjust procedures.

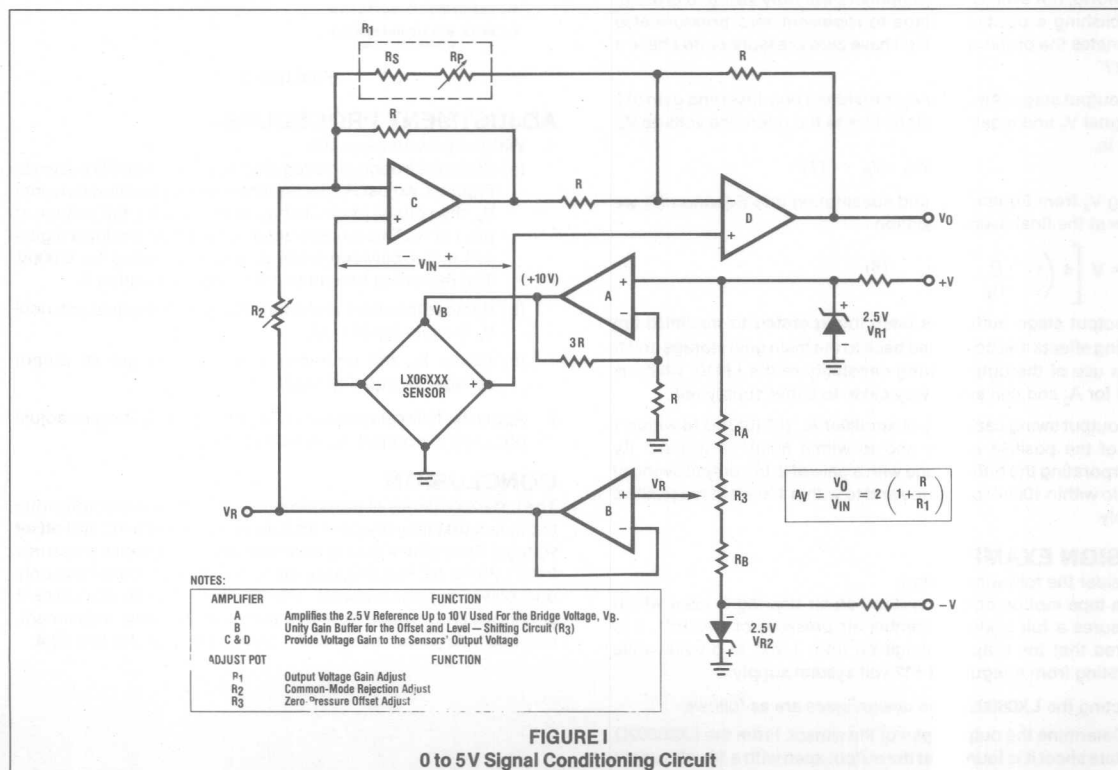
THE SOLUTION

To solve this problem, Sensym developed the LX06XXX Series, which, when used with the signal conditioning circuitry such as that contained in this application note, provides a low cost but precision solution. This application note describes a circuit,

using dual supplies, which can be used with any of the LX-06XXX series to provide a temperature compensated 0 to 5V_{DC} output signal. This output is compatible with many common A/D converters as well as being compatible with other signal conditioning options, such as 4 to 20mA current loops.

The LX06XXX series features a piezoresistive IC sensor element in conjunction with a passive hybrid compensation network. Using this thick-film hybrid compensation network, the LX-06XXX family solves the most difficult portions of the signal conditioning, namely, the span tolerance, the span temperature compensation, and offset calibration. These parameters are factory adjusted using computerized laser trimming techniques. This results in a family of devices for use in the 1psi to 100psi range, whose output signal can be easily amplified by user-supplied circuitry.

Figure I shows a functional block diagram of one such low cost amplifier circuit. The only active components required are a quad op amp and two voltage references. This circuit is easy to manufacture in volume production, as it features a simple non-interactive adjust procedure which can be performed at room temperature. It is also very versatile in that it can be operated over a wide range of supply voltages, from $\pm 12V_{DC}$ to $\pm 18V_{DC}$.



The circuit shown in Figure I allows independent adjustment of the output zero-pressure voltage, amplifier common-mode rejection, the output offset voltage, and the span.

CIRCUIT DESCRIPTION

The voltage across the sensor bridge is established by reference voltage V_R , which sets the voltage at the non-inverting input of amplifier A at 2.5V. This voltage is then amplified to provide 10V across the sensor bridge which is then independent of changes in supply voltage.

The output arms of the sensor bridge are connected to the non-inverting inputs of gain amplifiers C and D to eliminate any loading of the sensor.

The sensor's zero-pressure output voltage is adjusted by summing an offsetting voltage (V_R) into the summing junction of amplifier C through resistor R_2 . This voltage, V_R , is inverted by amplifier C and again by amplifier D, so the overall gain to V_R from input to output, V_O , is unity. With the circuit values shown in Figure II, the voltage, V_R , can be set by adjusting R_3 anywhere in the range from $-0.25V$ to $+0.25V$. If a voltage outside this range is needed, a simple change in values of the resistor string between the two zeners will allow for V_R ranging between $+2.5V$ and $-2.5V$.

The voltage gain is set by adjusting resistor R_1 . To set a full-scale span of 5V for the various LX06XXX devices, different values for resistor R_1 and the associated gains are shown in Table 1.

TABLE 1
Selected Gain Resistor/Pot Combinations for 5V Span
for individual LX06XXX Devices

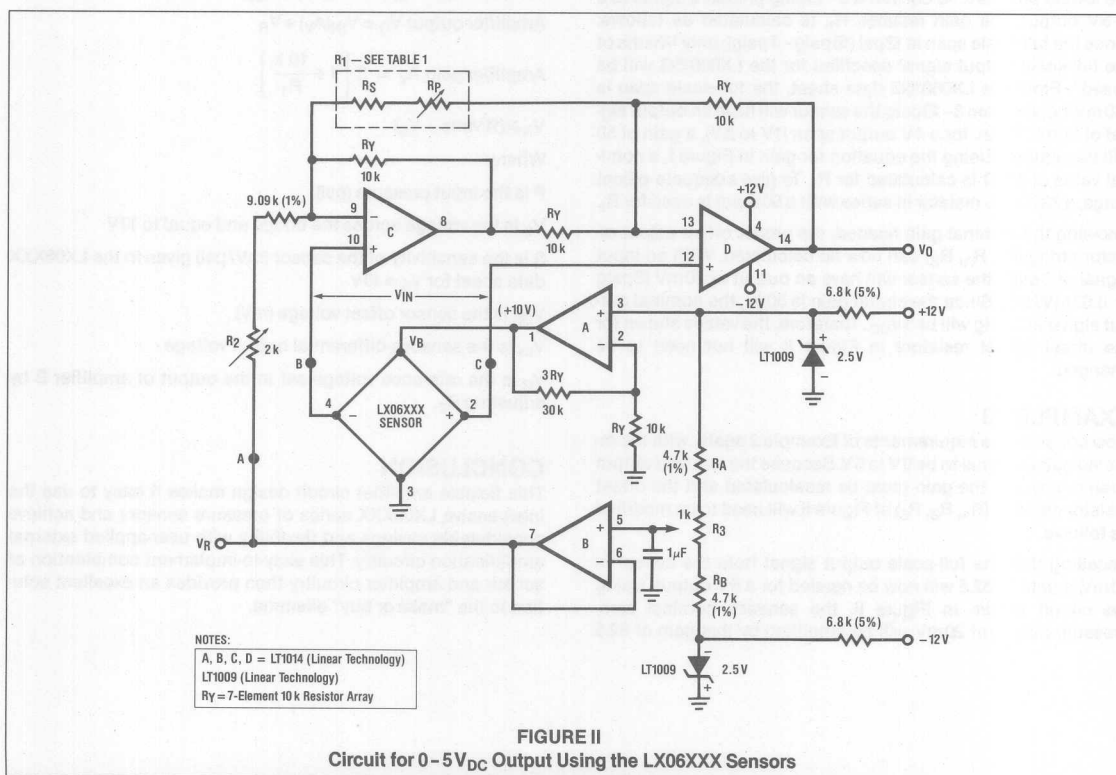
DEVICE	R_S	R_P	NOMINAL GAIN
LX06001	90.9 Ω	50 Ω	175
LX06002	140 Ω	50 Ω	125
LX06005	182 Ω	50 Ω	100
LX06015	392 Ω	50 Ω	50
LX06030	294 Ω	50 Ω	65
LX06100	536 Ω	100 Ω	35

R_S — closest value 1% resistors are shown.

R_S and R_P combined make up R_1 shown in Figure I.

ADJUSTMENT PROCEDURE: SEE FIGURE II

- To adjust common-mode rejection:
Short bridge arms together (Point B to Point C)
Short Point A to GND
Adjust R_2 for $V_O = 0V$
- To adjust output offset voltage:
Remove above shorts.
Apply lowest pressure.
Adjust R_3 for $V_O = 0V$ or desired voltage that represents the lowest pressure.



3) To adjust gain (span):

Set $P = P_{MAX}$ (Full-Scale Pressure)

Adjust R_1 for $V_O = 5V_{DC}$, or desired full-scale pressure voltage.

*For precision applications, Step 2 can be repeated after completion of Step 3. This may correct for a maximum offset shift during Step 3 of $200\mu V$.

EXAMPLE #1

Many medical and industrial applications using compressed air require a 0V to 5V output for a 0 to 30psig pressure signal. To achieve this, use the value for the gain resistor/pot combination indicated in Table 1 for the LX06030G (294Ω for fixed resistor R_S and 50Ω for the pot, R_P). Using these values in the circuit shown in Figure II and performing the adjust procedure as outlined will result in a circuit which gives a 0V to 5V output for a 0–30psig pressure input signal.

EXAMPLE #2

In many pneumatic control systems, the control pressure used is 3 to 15psig. The circuit shown in Figure I is easily used to convert this 3 to 15psig pressure signal to any desired output voltage; for example 0–5 V_{DC} or 1–5 V_{DC} .

Many applications prefer using a non-zero output voltage to represent the lowest pressure, such as 1–5 V_{DC} , to eliminate a ground fault condition on the output from being interpreted as the lowest pressure. To convert a 3–15psig pressure signal to a 1–5V output, the gain resistor, R_1 , is calculated as follows: Since the full-scale span is 12psi (15psig – 3psig), only $\frac{1}{12}$ of the full-scale output signal specified for the LX06015G will be "used". From the LX06015G data sheet, the full-scale span is 100mV, hence, from 3–15psig the sensor will have an output signal of 80mV. Then, for a 4V output span (1V to 5V), a gain of 50 will be required. Using the equation for gain in Figure I, a nominal value of 416Ω is calculated for R_1 . To give adequate adjust range, a 392Ω 1% resistor in series with a 50Ω pot is used for R_1 .

Knowing the nominal gain needed, the proper offset adjust resistor string (R_3 , R_A , R_B) can now be calculated. With an input signal of 3psig, the sensor will have an output of 20mV ($3\text{psig} \times 6.67\text{mV/psi}$). Since the circuit gain is 50, the nominal output signal at 3psig will be 1 V_{DC} . Therefore, the values shown for the offset adjust resistors in Figure II will not need to be changed.

EXAMPLE #3

Now consider the requirements of Example 2 again, with the required output signal to be 0V to 5V. Because the required output span is now 5V, the gain must be recalculated and the offset resistor network (R_A , R_B , R_3) of Figure II will need to be modified as follows.

Recalling that the full-scale output signal from the sensor is 80mV, a gain of 62.5 will now be needed for a 5V output. Using the circuit shown in Figure II, the sensor's nominal zero-pressure output of 20mV will be amplified by this gain of 62.5

resulting in an output of 1.25V ($20\text{mV} \times 62.5 = 1.25\text{V}$) at 3psig. Level shifting this 1.25V back to the required 0V can be easily accomplished by changing the value of resistor R_B . If R_B is changed to 825Ω , voltage V_R can be adjusted from –1.1V to –1.85V. This will allow adequate range to level-shift the attendant 3psig output signal (1.25V) to 0V.

Caution:

One circuit limitation which must be considered here is that in order to avoid limitations in the output swing of amplifier C, the reference voltage, V_R , must always meet the following inequality:

$$V_R > (11\text{Volts} - V_S).$$

For example 3 above, the positive supply, V_S , must be at least +12.25V or amplifier C will not be able to follow the signal if $V_R = -1.25\text{V}$. Using this same inequality, it can be seen that for $\pm 15\text{V}$ operation, V_R can be any voltage greater than –4V.

DESIGN EQUATIONS

Obviously, any number of output voltage combinations representing the lowest and highest pressures of interest can be achieved by modifying the offset and/or gain resistors. To calculate the resistor values for various pressure ranges and output signals other than those shown, the following design equations can be used:

$$\text{Sensor output } V_{IN} = (P \cdot V_B \cdot S) \pm V_{OS}$$

$$\text{Amplifier output } V_O = V_{IN}(A_V) + V_R$$

$$\text{Amplifier gain } A_V = 2 \left[1 + \frac{10\text{ k}}{R_1} \right]$$

$$V_R \geq (11\text{Volts} - V_S)$$

Where:

P is the input pressure (psi)

V_B is the voltage across the bridge and equal to 10V

S is the sensitivity of the sensor (mV/psi) given in the LX06XXX data sheet for $V_S = 10\text{V}$

V_{OS} is the sensor offset voltage (mV)

V_{IN} is the sensor's differential output voltage

V_R is the reference voltage set at the output of amplifier B by adjusting R_3 .

CONCLUSION

This flexible amplifier circuit design makes it easy to use the inexpensive LX06XXX series of pressure sensors and achieve considerable savings and flexibility with user-applied external amplification circuitry. This easy-to-implement combination of sensor and amplifier circuitry then provides an excellent solution to the "make or buy" dilemma.

Designing a Low Cost 4-20 mA Pressure Transmitter

By: Duane Tandeske

INTRODUCTION

For a variety of reasons, one of the most popular output signals for pressure sensing devices in industrial applications is a 2-wire 4-20mA current loop. The benefits of this transmission method are: (1) it uses the same two wires to transmit both signal and device power, hence saving conductors and space; (2) it provides a low impedance transmission path, and is therefore less susceptible to induced noise pickup; (3) the transmission of current eliminates the concern of IR drop down the line, making the signal relatively independent of line resistance and line length. Although these benefits have made 4-20mA transmission extremely popular, the major drawback of these pressure transmitters has been their high cost, even though low cost IC pressure sensors are now available. What is needed then is the design of a simple and inexpensive circuit that will convert the differential output voltage from a low cost pressure sensor to the desired 4-20mA output. This application note discusses the design of a circuit which performs this task.

THE SOLUTION

The key design features which need to be met are:

1. The basic sensor and signal conditioning circuitry must be inexpensive.
2. The adjust procedure must be simple, noninteractive and performed at room temperature.
3. The complete circuit has to be as small as possible to allow for easy packaging and installation at remote pressure sensing locations.

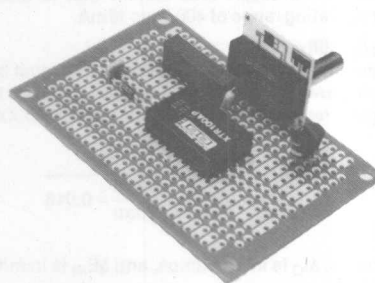
These criteria lead to selection of the following components:

LX06XXX Series Pressure Sensor

The LX06XXX Series of pressure sensors were chosen because of: (1) Their low cost and availability in the common pressure ranges; from 0-1psi to 0-100psi. (2) The devices are provided with span temperature compensation as an integral part of the device, as it is precalibrated at the factory. Hence, the user does not have to perform this often difficult task which requires combined pressure and temperature cycling: (3) The LX06XXX series are also provided with factory preset zero and full-scale pressure calibration. Thus, for many applications only a circuit null

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adjust at ambient pressure and room temperature need be performed by the user. From a signal conditioning standpoint, the LX06XXX pressure sensors provide an ideal trade-off between low cost and factory-performed signal conditioning.

XTR100 (Burr Brown Corp.)

Although there are many ways to convert the differential output voltage signal of the LX06XXX Series sensors to a single-ended output, and then to a 4-20mA current, the XTR100 provides an excellent single component solution. The XTR100 contains a high accuracy instrumentation amplifier, a voltage-controlled current source, and two matched 1mA current references. It is designed specifically to convert a low level differential signal to a 4-20mA output.

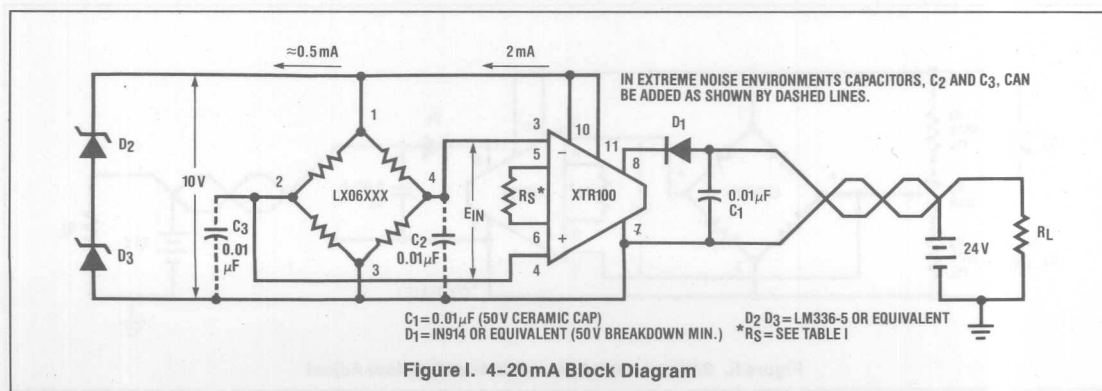
A functional block diagram of a 4-20mA pressure transmitter using these components is shown in Figure 1.

DESIGN CONSIDERATIONS

The following discussion gives some of the key factors which should be considered in this circuit design.

XTR100 Input Biasing

For linear operation, the XTR100 inputs (pins 3 and 4 shown in Figure 1) must be biased between +4V to +6V with respect to pin 7. Since the common-mode voltage of the LX06XXX Series outputs will nominally be equal to one half the voltage across the sensor bridge, applying 10V across the LX06XXX will bias the nominal input voltage to the XTR100 at +5V with respect to pin 7.



The XTR100 has two 1mA current sources (pins 10 and 11) available to power the LX06XXX sensor. With a typical input impedance of 7k Ω for the LX06XXX, the sensor will draw about 1.5mA and the remaining 0.5mA will be used to bias reference diodes D2 and D3. Two LM336Z-5's are used for the reference diodes because the 500 μ A bias current that is available is within their operating range of 400 μ A to 10mA.

Setting the Amplifier Gain

For an output of 4 to 20mA, the full-scale span must be set to 16mA (20mA - 4mA). The following equation is used to determine the gain resistor, R_S , for any of the LX06XXX Series devices.

$$R_S = \frac{40}{\frac{\Delta I_O}{\Delta E_{IN}} - 0.016} = \frac{40}{\frac{0.016}{\text{Span}} - 0.016}$$

Where:

R_S is in ohms, ΔI_O is in milliamps, and ΔE_{IN} is in millivolts.

Various values of R_S have been tabulated for the standard LX06XXX pressure ranges and are shown in Table I.

System Accuracy

(A) Good

If a static accuracy of $\pm 5\%$ can be tolerated, the closest 1% resistor value to the nominal values shown in Table I can be used and the circuit design is then free of adjustments.

(B) Better

To achieve better accuracy and eliminate the errors due to variances in span, R_S should be replaced by a pot, R_P , in series with a fixed resistor, R_A , as shown in Table I. The span is then adjusted as follows:

Span Adjust Procedure

1. Apply zero pressure and note output (approx. 4mA).
2. Apply full-scale pressure and adjust pot R_S for a 16mA change in the output current.

(C) Best

To achieve the best accuracy, the offset errors should also be nulled out. The circuit shown in Figure II should then be used with the following adjust procedure:

Offset and Span Adjust Procedure

1. With zero pressure applied, adjust pot R_2 for 4.0mA at the load.
2. Apply full-scale pressure. Adjust pot R_P for an output of 20.0mA at the load.
3. Apply zero pressure and recheck for 4.0mA.

TABLE I
Selected Gain Resistors (R_S)
for Individual LX06XXX Devices

Device	Pres. Range psi	Static Accuracy		Nom. Values of R_S	R_S	
		Offset	Lin. His.		R_A	R_P
LX06001	0-1	$\pm 7.1\%$	$\pm 1.6\%$	72 Ω	50 Ω	50 Ω
LX06002	0-2	$\pm 5.0\%$	$\pm 1.6\%$	104 Ω	75 Ω	50 Ω
LX06005	0-5	$\pm 2.0\%$	$\pm 1.6\%$	131 Ω	82 Ω	100 Ω
LX06015	0-15	$\pm 1.0\%$	$\pm 1.1\%$	278 Ω	232 Ω	100 Ω
LX06030	0-30	$\pm 1.3\%$	$\pm 0.6\%$	214 Ω	150 Ω	100 Ω
LX06100	0-100	$\pm 0.7\%$	$\pm 0.6\%$	407 Ω	301 Ω	200 Ω

R_A = 1% Metal Film, R_P = Mult. Turn Pot (Metal Film or Cermet)

CIRCUIT LAYOUT CONSIDERATIONS

The complete circuit is quite small and can be easily constructed on a 2 inch square PC board. The 0.01 μ F capacitor, in conjunction with diode D1, will prevent circuit damage due to transients or reverse polarity and should be placed as close to the XTR100 package as possible.

The lead lengths from the sensor output to pins 3 and 4 of the XTR100 should be kept as short as possible, and resistor R_S should be located so as to minimize its lead lengths to pins 5 and 6.

DESIGN EXAMPLE #1

In a typical industrial control application, a 4-20mA output is needed for a 0 to 15psig input pressure. This example uses an LX06015G to demonstrate the gain calculation and adjustment procedure needed to obtain $\pm 5\%$ accuracy over a 0 $^{\circ}$ C to 50 $^{\circ}$ C temperature range. R_S is calculated as follows:

$$R_S = \frac{40}{\left(\frac{16 \text{ mA}}{100 \text{ mV}}\right) - 0.016} = \frac{40}{0.144} = 278 \Omega$$

To achieve better accuracy and allow for actual component tolerance, a 232 Ω 1% resistor in series with a 100 Ω multturn cermet pot is used. This will provide the ability to trim for the variances in span. The complete circuit is identical to the circuit shown in Figure I.

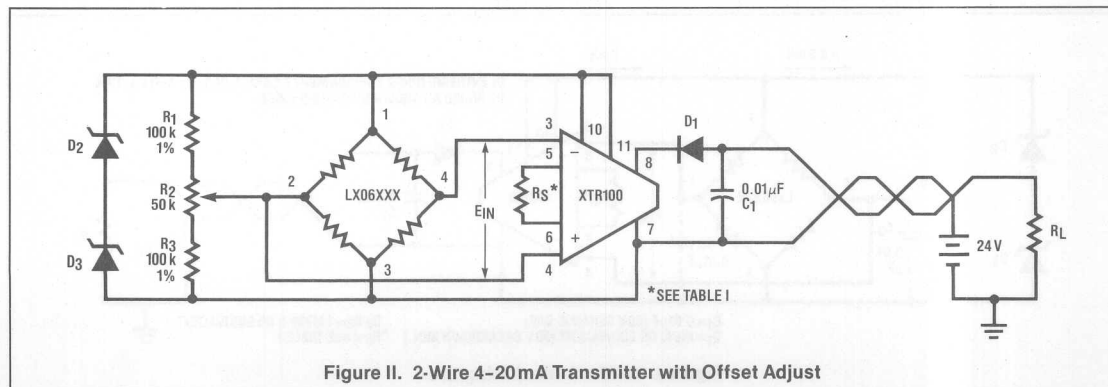


Figure II. 2-Wire 4-20mA Transmitter with Offset Adjust

PERFORMANCE AND ERROR ANALYSIS

For example #1, the overall circuit performance characteristics can be calculated as a percentage of full-scale span:

TRANSMITTER SPECS.

0-15 psig

Transducer Span = 100 mV

Transmitter Span = 16 mA

OFFSET ERROR:

LX06015G = ± 1 mV Max.

XTR100 = $\pm 50 \mu\text{V}$

$$\text{Maximum Offset Error} = \frac{1.05 \text{ mV}}{100 \text{ mV}} = \pm 1.05\%$$

STATIC ERROR:

Offset Error = $\pm 1.05\%$

Linearity LX06015G = $\pm 1.0\%$ FS Typ.

Repeatability and Hysteresis = 0.1% FS Typ.

Linearity XTR100 = 0.01% Max.

$$\text{Total Static Error} = \pm 2.16\% \text{ FS Typ.}$$

OFFSET TEMPERATURE ERRORS:

LX06015G = ± 2 mV Typ. (0 to 50°C)

XTR100 = $\pm 50 \mu\text{V}$

$$\text{Typical Offset TC Error} = \frac{2.05 \text{ mV}}{100 \text{ mV}} = \pm 2.05\%$$

SPAN TEMPERATURE ERRORS (0°C to 50°C):

LX06015G = $\pm 1.5\%$ FS Typ.

XTR100 = $50^\circ\text{C} \times 100 \text{ ppm}/^\circ\text{C} = \pm 0.5\%$

$$\text{Total Span Temp. Error} = \pm 2.0\% \text{ FS Typ.}$$

OVERALL TEMPERATURE EFFECT (0°C to 50°C):

Offset = $\pm 2.05\%$ Typ.

Span = $\pm 2.0\%$ FS Typ.

$$\text{Total} = \pm 4.05\% \text{ Typ.}$$

Typical circuit performance curves are shown in Figures III-VI.

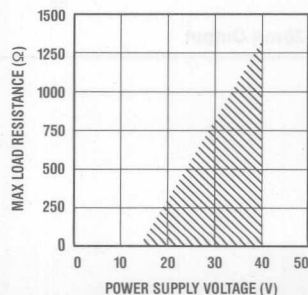


Figure III. Power Supply Operating Range

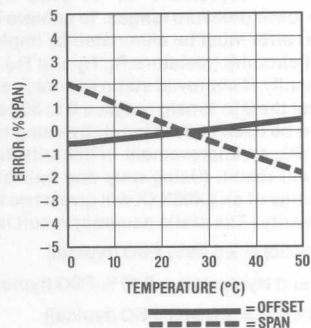


Figure IV. Offset and Span vs. Temperature

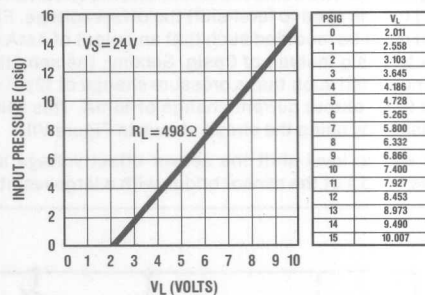


Figure V. Accuracy

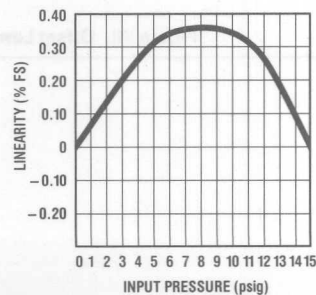


Figure VI. Linearity

DESIGN EXAMPLE #2 — Higher Accuracy

Table I gives the static accuracy and span adjustment networks for the six pressure ranges of the LX06XXX Series transducers. This table indicates that the percentage error contributed by the unadjusted offset is quite significant, especially in the lower pressure ranges. To achieve better accuracy, the offset error must be eliminated by implementing the offset adjust circuitry (resistors R_1 , R_2 and R_3) shown in Figure II. Additionally, if improved static accuracy and linearity is required over the 0 to 15 psig range, a 0 to 30 psig device (LX06030G) could be used in the circuit. By using the higher pressure LX06030G, an improvement in linearity, from 0.5% to 0.25% FSO, will result. (Using only one half of the full-scale pressure range of an LX06XXX will give a two to one improvement in linearity.) The static accuracy result is:

Linearity (LX06030) = $\pm 0.25\%$ FSO (typical)

Repeatability and Hysteresis = 0.10% FSO (typical)

Linearity (XTR100G) = $\pm 0.01\%$ FSO (typical)

Total Static Error = $\pm 0.36\%$ FSO (typical)

DESIGN EXAMPLE #3 — Pneumatic Control

Many pneumatic applications use a 3 to 15 psig input pressure signal which must be converted to a 4–20 mA output. Although this is slightly more difficult than using a zero psi based signal, with two minor modifications the circuit shown in Figure I can be used to level-shift the offset voltage. First, the circuit must be modified such that an output of 4 mA corresponds to 3 psig instead of 0 psig. Second, the sensitivity must be increased such that a pressure change of 12 psi corresponds to an output current change of 16 mA. This will be accomplished by using the circuit shown in Figure VII.

A simple way to level shift the sensor offset voltage is to shunt pins 1 and 4 of the sensor bridge with a large resistor.

Using the LX06015G, the output needs to be shifted by approximately 20 mV so that the 3 psi signal corresponds to a 4 mA circuit output. Typically, a 250 k Ω to 750 k Ω resistor will be needed as a level shift resistor (R_{LS}). The exact value of this resistor is dependent on the individual internal compensation circuitry of each LX06015G and the shunt resistor will therefore need to be individually selected or trimmed for each device.

Using the LX06015G, the span for a 3 to 15 psig signal is 80 mV ($12 \text{ psi} \times 6.67 \text{ mV/psi}$). This corresponds to a span setting resistor, R_S , of 217 Ω . The calculation is shown below:

$$R_S = \frac{40}{\left(\frac{16 \text{ mA}}{80 \text{ mV}}\right) - 0.016} = 217 \Omega$$

To allow adequate adjustment range, a 191 Ω 1% resistor in series with a 50 Ω is recommended.

Level Shift and Span Adjust Procedure

1. With 3 psig pressure applied, adjust R_{LS} for 4.0 mA at the load (see Figure VII).
2. Apply 15 psig pressure. Adjust R_S for an output of 20.0 mA at the load.
3. Apply 3 psig pressure and recheck for 4.0 mA.

Using the circuit shown in Figure VII and individually selecting the proper offset shunt resistor will result in a low cost 4–20 mA transmitter for a 3–15 psig input pressure.

CONCLUSION

By combining Sensym's LX06XXX Series with the Burr Brown XTR100, a simple, two-wire 4–20 mA current-loop transmitter can be designed. Because the design has a minimum number of components and adjustments, it provides a very cost effective solution to many industrial pressure sensing applications.

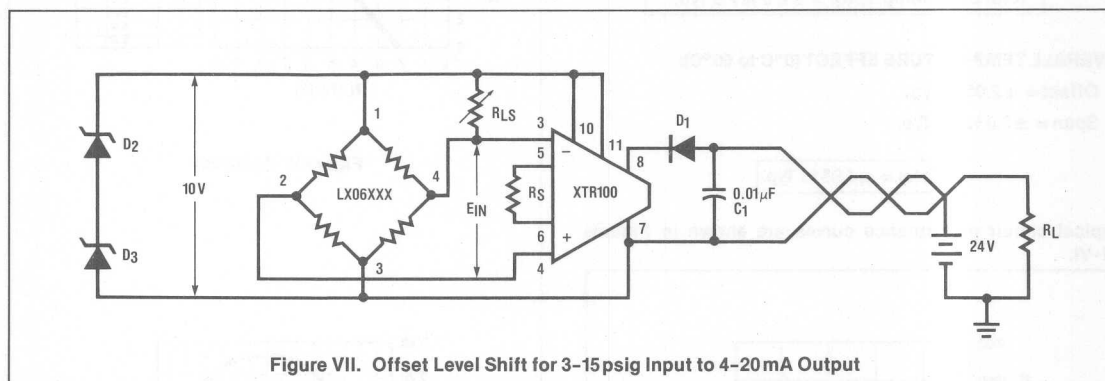


Figure VII. Offset Level Shift for 3–15 psig Input to 4–20 mA Output

Low-Cost Digital Conversion for IC Pressure Transducers

By Roland Lee

INTRODUCTION

As more process control systems become computerized, there is an increased need to provide a digitized output signal for pressure monitoring. Because pressure transducers typically provide analog output signals, an A/D converter is needed to convert the analog pressure transducer signal to the required digital signal.

Although many different types of "digital" outputs are available (serial, parallel, 8-bit, 12-bit, etc.), this application note discusses the interface of a low-cost 8-bit parallel A/D converter to the LX06XXX family of pressure transducers. With 8 bits of resolution, errors can be held within 1 LSB, i.e. $\pm 0.39\%$ FSO. While A/D converters with more resolution are available, many pressure applications do not require extreme accuracy and hence do not justify the higher cost associated with higher accuracies. However, the design technique can be easily extended to a serial output data format or to higher resolution converters as required.

THE SENSOR AND AMPLIFIER

The LX06XXX series features a piezoresistive IC sensor element in conjunction with an integral passive hybrid calibration and temperature compensation network. This results in a family of devices for use in the 1psi to 100psi range, whose output signal can be easily amplified to the necessary input voltage

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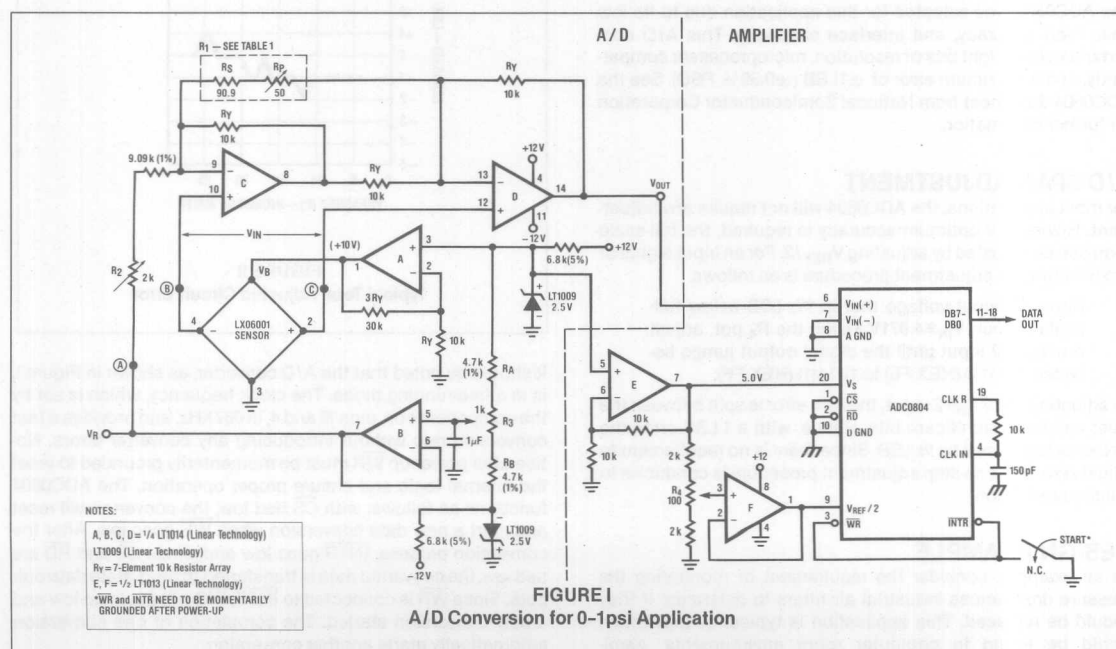
requirements of the A/D converter. The circuit shown in the left half of Figure 1 performs this amplification and provides a 0 to 5V signal which is compatible with the input requirements of most A/D converters (see SSAN-18 for details on this amplifier design). Although resistor values for the 0-1psi application are shown in Figure 1, Table 1 shows the resistor values for R_1 for various LX06XXX sensors to obtain the required 5V span.

TABLE 1
Selected Gain Resistor/Pot Combinations for 5V Span
for Individual LX06XXX Devices

DEVICE	R_S	R_P	NOMINAL GAIN
LX06001	90.9 Ω	50 Ω	175
LX06002	140 Ω	50 Ω	125
LX06005	182 Ω	50 Ω	100
LX06015	392 Ω	50 Ω	50
LX06030	294 Ω	50 Ω	65
LX06100	536 Ω	100 Ω	35

R_S — closest value 1% resistors are shown.

R_S and R_P combined make up R_1 shown in Figure 1.



A notable feature of this particular amplifier design is that the adjustments for common-mode rejection, span, and offset are all non-interactive, and as a result, volume manufacturing is simplified. The adjustment procedure is as follows:

1. To adjust common-mode rejection:
Short the bridge arms together (Point B to Point C)
Short Point A to ground
Adjust R_2 so that $V_{OUT} = 0.0V$
2. To adjust the offset voltage:
Remove the bridge arm short.
Apply the low pressure that is to represent zero volts and adjust R_3 so that $V_{OUT} = 0.0V$
3. To adjust span:
Apply the full-scale pressure.
Adjust R_P until $V_{OUT} = 5.00V$

There are no other calibrations necessary, since the thermistor networks built into the LX06XXX will provide temperature compensation.

To the basic amplifier design of Figure 1, the only additional components required are those associated with amplifiers E and F. Amplifier E is used to give a non-inverting gain of two (2) and amplifies the 2.5V zener reference to provide a +5V supply voltage to the A/D converter. Amplifier F uses the +5V in conjunction with the resistor divider string, and resistor R_3 to set the reference voltage for the A/D converter. The advantage of using amplifiers E and F in this manner is that the +2.5V zener (LT1009) has also been used to establish V_B , the +10V supply at the top of the pressure transducer bridge. Now the LT1009 becomes the master reference in the system. Should the reference voltage change, the voltage at the top of the bridge will change, but so will the reference to the A/D converter. In this manner the circuit is ratiometric to the LT1009 reference and the output of the A/D will not be affected by changes in the supply voltages or the reference voltage.

A/D CONVERSION

The ADC0804 was selected for this application due to its low cost, high accuracy, and interface simplicity. This A/D converter provides eight bits of resolution, microprocessor compatibility, and a maximum error of $\pm 1\text{LSB}$ ($\pm 0.39\%$ FSO). See the ADC0804 datasheet from National Semiconductor Corporation for further information.

A/D SPAN ADJUSTMENT

For most applications, the ADC0804 will not require any adjustment. However, if optimum accuracy is required, the full-scale span can be adjusted by adjusting $V_{REF}/2$. For an input signal of 0 to 5V the span adjustment procedure is as follows:

Apply an input voltage that is $1\frac{1}{2}$ LSB below full-scale output; $V_{IN} \approx 4.971V$. Using the R_4 pot, adjust the $V_{REF}/2$ input until the digital output jumps between 1111 1110 (HEX FE) to 1111 1111 (HEX FF).

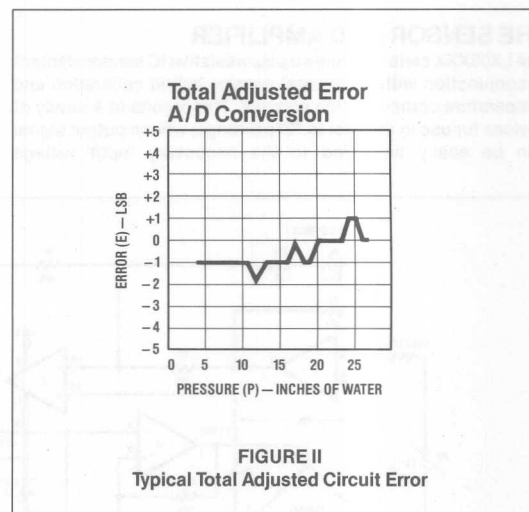
By adjusting the $V_{REF}/2$ input, the zero error is split between the most and least significant bits. Hence, with a 1 LSB error, the zero error is reduced by $\frac{1}{2}$ LSB. Since there is no requirement to adjust zero, this one-step adjustment procedure is conducive to volume production.

DESIGN EXAMPLE

As an example, consider the requirement of monitoring the pressure drop across industrial air filters to determine if they should be replaced. This application is typical of that which would be found in computer room environments, semi-

conductor processing areas, air conditioning, and the like, where air filters are used to trap dust particles. For example, a 1psi (28 inches of water column pressure) drop across the filter may indicate that the filter was clogged and needed replacement, whereas a drop of 6 inches of water column pressure would represent a clean filter, and zero pressure drop would indicate that the filter has not been put in place! It is now a simple task for a microprocessor to keep track of the filter, with an output from the A/D converter of 0000 0000 representing the filter has been omitted, 0011 0111 representing a clean filter, and 1111 1111 a blocked or clogged filter. Codes in between can represent degrees of blockage and signal cautionary or change filter indicators. Since the LX06001D has a full-scale exactly corresponding to the 1psi (28 inches W.C.) pressure range of interest, the resistor values of $R_S = 90.9\Omega$ and $R_P = 50\Omega$ pot shown in Table 1 can be used. The complete circuit is shown in Figure 1. After following the aforementioned adjustment procedure to set offset, span, and $V_{REF}/2$, the output of the A/D converter will change from 0000 0000 to 1111 1111 for a 0-1psid pressure input.

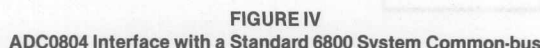
Figure 2 shows the total measured error of the sensor and the A/D converter. A worst case error analysis would indicate that the sensor could contribute as much as $\pm 1.5\%$ FSO of error due to non-linearity which, when combined with a worst case error of 0.39% FSO from the converter, would result in a total error of $\pm 1.9\%$ FSO or approximately ± 4 LSB. In Figure 2, the maximum error of -2 LSB is well within the worst case ± 4 LSB error analysis, and represents an error of less than 1% FSO.



It should be noted that the A/D converter, as shown in Figure 1, is in a free-running mode. The clock frequency, which is set by the components on pins 19 and 4, is 667 kHz, and provides a fast conversion rate without introducing any converter errors. Notice after power-up $\overline{WR}$ must be momentarily grounded to reset the internal logic and ensure proper operation. The ADC0804 functions as follows: with $\overline{CS}$ tied low, the converter will reset and start a new data conversion when $\overline{WR}$ goes low. After the conversion process, $\overline{INTR}$ goes low and, since $\overline{CS}$ and $\overline{RD}$ are tied low, the converted data is transferred to the 3-state data outputs. Since $\overline{WR}$ is connected to $\overline{INTR}$, $\overline{WR}$ will again go low and a new conversion started. The completion of one conversion automatically starts another conversion.

Although there are many ways to use the ADC0804, microprocessor interfaces are desirable for systems where the output data is to be stored in memory or manipulated by software. Figure III shows the A/D converter connected to an INS8048 microcontroller (see the INS8048 datasheet from National Semiconductor Corporation). By using an external I/O line on the 8048 as a chip select signal, and by having the data memory-mapped into the microcontroller, interface logic as well as address decoding is eliminated. The A/D converter can also be connected to a standard 6800 common bus as shown in Figure IV. This bus system is compatible with all 6800 and 6500 microprocessor derivatives. Although address decoding is necessary for Figure IV, a decoded 4.5 line is readily available as a chip select line, provided there are no other devices addressed at HEX addresses 4XXX or 5XXX.

The LX06XXX family of pressure sensors, when combined with the ADC0804 and simple signal conditioning circuitry, can provide an accurate low-cost "digital" pressure sensor.



A Simple Bar Graph Pressure Display

By Duane Tandeske

INTRODUCTION

Many applications that require pressure sensors and pressure monitoring devices also need a display to provide an easy-to-read determination of pressure. Historically, this has been available only with mechanical gauges. Now, using an integrated circuit pressure sensor in combination with an LED bar graph display, one can get a reliable low cost pressure display that has all the advantages of IC technology; no moving parts for high reliability, high accuracy, high cycle life, small size, and ease of interface with microprocessor systems for control. This application note describes the design details for a pressure indicator system incorporating Sensym's low cost integrated circuit pressure sensor and a 10-segment LED bar graph display and driver module.

DESIGN CRITERIA

To make a pressure display system which could replace many of the old mechanical gauges in addition to being useful in a wide variety of new applications, this system was designed to meet the following criteria:

- Low Cost
- Operation from a single supply
- Compact size
- Easy to Read
- Easy to Manufacture

To make the design as low cost as possible, we used the SPX series sensors. These low cost monolithic sensors give accu-

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rate readings for pressures between 0 to 1psi and 0 to 30psi so there are a wide variety of useful applications including:

- Monitoring pressure drops across industrial liquid filters in food processing, chemical processing, and sewage and filtration plants. (Pressure range: 0-30psid.) Here the user would be alerted when to change the filter or backwash the system.
- Monitoring pressure drops across industrial gas filters, including air conditioning, gas separation, flow monitoring, and high vacuum systems. (Pressure range: 0.0-0.5psid.)
- Turbo boost indicators on automobile engines. (Pressure range: -6 to +14psig.)
- Other applications include medical instrumentation and filtration equipment, computer filters, clean rooms, and an assortment of home appliances.

The basic design of this system is quite simple, as shown in Figure 1. The key features of this specific design are in its ease of adjustment and use of reliable, proven off-the-shelf components. To keep costs and number of components to a minimum, the SPX series pressure sensor is combined with the NSM3914 LED driver/display module from National Semiconductor. As shown in Figure 1, only an amplifier is then needed to interface these two components. To complete the design, a resistor network is added for offset adjust since this is an unadjusted sensor and span temperature compensation has also been included to minimize errors over temperature.

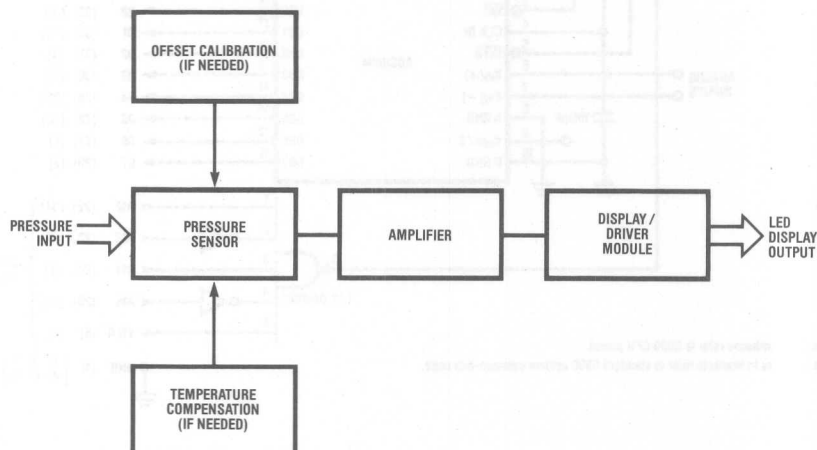


FIGURE 1
Pressure Display Simple Block Diagram

The specific circuit described in the following example can be easily modified to accommodate a wide variety of full-scale pressure ranges simply by changing the gain of the amplifier. See Table 1 for specific gain resistor values for the SPX series. Also, since this circuit performs full calibration and temperature compensation, the design can very easily be adapted to Sensym's other low cost series, such as the SX and LX06xxx devices.

TABLE 1
Nominal Gain Resistor Value for 10 LEDs' Full-Scale Range

PRESSURE RANGE	DEVICE	R _S	
		R _G	R _P
0-1psi	SPX50DN	909Ω	2k
0-10psi	SPX50DN	909k	20k
0-15psi	SPX100	6.9k	20k
0-30psi	SPX200	6.9k	20k

Notes:

- 1) $R_S = \frac{2 R_N}{A_V - 2}$
- 2) Calculation assumes $R_N = 100 \text{ k}\Omega$.

DESIGN EXAMPLE — A LOW COST OIL FILTER MONITOR

To illustrate this low cost sensor display module, this example gives a specific application on monitoring the pressure drop across a typical industrial oil filter to determine its replacement

status. A clean filter would typically have a 4 psid pressure drop, however, as dirt accumulates, the pressure drop across the filter progressively increases. At a pressure drop of 7 psid, the filter should be cleaned or replaced. Additionally, for this application, the pressure sensing system needs to operate from a 5V power supply and over a temperature range of 0-50°C.

Sensor Selection: The lowest cost sensor available in the pressure range of 0-7psid is the Sensym SPX50D(N). Although specified from 0-7.25psid, the SPX50D(N) will actually operate linearly up to 10psid. The expected output span over 0-10psid will be 55-131mV as determined from the following calculations:

Minimum Span (from SPX data sheet) is given by

$$\frac{800 \mu\text{V/kPa}}{0.145 \text{ psi/kPa}} (10 \text{ psi}) = 55 \text{ mV}$$

Maximum Span is given by

$$\frac{1900 \mu\text{V/kPa}}{0.145 \text{ psi/kPa}} (10 \text{ psi}) = 131 \text{ mV}$$

This span variation will be "calibrated out" by adjusting the amplifier gain. In addition to this span tolerance, the sensor's offset or zero pressure output can also vary from 0-35mV. This is adjusted by shunting one arm of the bridge as shown in Figure II. Aside from this calibration, the other major error source which must be compensated for in most applications is the sensor's output changes due to temperature.

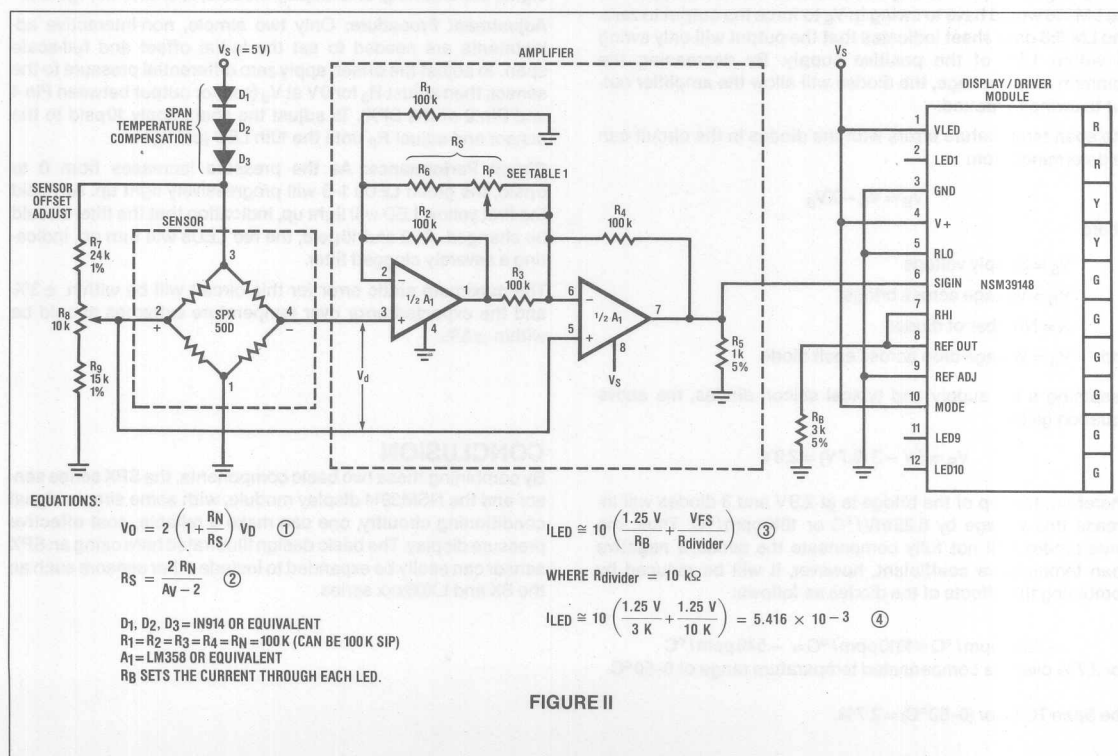


FIGURE II

Temperature Effects: The SPX50D's offset temperature error is typically $15\mu\text{V}/^\circ\text{C}$ (see SPX data sheet). To calculate the worst case offset error, we must assume a minimum sensitivity sensor. The worst case offset TC will be 1.36%, as shown below.

$$\frac{15 \times 10^{-6} \text{ V}/^\circ\text{C}}{55 \times 10^{-3} \text{ V}} \cdot (50^\circ\text{C}) (100) = 1.36\%$$

where

$$15 \times 10^{-6} \text{ V}/^\circ\text{C} = \text{Offset TC}$$

$$55 \times 10^{-3} \text{ V} = \text{Minimum Span}$$

$$50^\circ\text{C} = \text{Temperature Range}$$

Since this error can be tolerated in this application, offset temperature compensation will not be required.

In addition to the offset error, the sensor's span error with temperature must also be determined and added to the offset error to give the maximum overall temperature error. Typically, the SPX sensor's span will decrease at $-2350\text{ppm}/^\circ\text{C}$. This error will be too large for some applications, however, it can be reduced substantially by adding three general purpose (IN914-type) silicon diodes (shown in Figure II) in series with the sensor bridge. Since each diode has a voltage drop of 0.7V and a TC of $-2500\text{ppm}/^\circ\text{C}$, and since the voltage across the entire diode/bridge network will remain constant, bridge voltage (V_B) will increase as the temperature increases, thereby partially compensating for the decrease in sensor sensitivity.

The diodes will also decrease the common-mode voltage of the SPX outputs which will allow the output of the amplifier to swing to ground (refer to Figure II). Without the diodes, pin 1 of the LM358 would have to swing to V_S to force the output to zero. The LM358 data sheet indicates that the output will only swing to within 1.5V of the positive supply. By decreasing the common-mode voltage, the diodes will allow the amplifier output to swing to ground.

The span temperature errors with the diodes in the circuit can be determined from

$$V_B = V_S - XV_d$$

where

$$V_S = \text{Supply voltage}$$

$$V_B = \text{Voltage across bridge}$$

$$X = \text{Number of diodes}$$

$$\text{and } V_d = \text{Voltage drop across each diode}$$

Assuming a 5V supply and typical silicon diodes, the above equation gives

$$V_B = 5\text{V} - 3(0.7\text{V}) = 2.9\text{V}$$

Therefore, the top of the bridge is at 2.9V and 3 diodes will increase this voltage by $5.25\text{mV}/^\circ\text{C}$ or $1810\text{ppm}/^\circ\text{C}$. Thus, the three diodes will not fully compensate the sensor's negative span temperature coefficient, however, it will be reduced by combining the effects of the diodes as follows:

$$-2350\text{ppm}/^\circ\text{C} + 1810\text{ppm}/^\circ\text{C} = -540\text{ppm}/^\circ\text{C}$$

or 2.7% over the compensated temperature range of 0-50°C.

$$\text{The Span TC Error (0-50}^\circ\text{C)} = 2.7\%.$$

The total temperature induced error will be the sum of the offset temperature error (1.36%) and the span temperature error (2.7%), which gives a total temperature induced error of 4.06%. This error corresponds to the lowest sensitivity sensor, thus it represents a worst case condition. Higher sensitivity components can potentially reduce this error to 3.2%.

Display Selection: For this example, the NSM39148 display was selected. This display features an arrangement of 6 green, 2 yellow, and 2 red LEDs, which can serve as an early warning of excessive filter degradation.

Amplifier Design: The dual op amp shown in Figure II was chosen because it operates well in applications where the common-mode input is near ground. It also features operation from a 5V supply, high input impedance, and an output swing from 0 to 1.2V.

In order to light all ten segments of the display, it is necessary to provide the NSM39148 an input signal from 0 to 1.2V. The first LED will turn on at 120mV, the second at 240mV, and so on, leading to 1.2V being required to turn on the 10th LED. The minimum and maximum output signals for the SPX50D is 55mV and 131mV, respectively, which will demand an amplifier gain between 9.16 and 21.8.

Using equation 2 from Figure II, the range of R_S is calculated to be from 10.1k to 27.9k. To cover this range, a fixed 9.09k 1% metal film resistor (R_6) was combined in series with a 20k multi-turn cermet pot (R_P).

Finally, a 1k resistor was placed from the output of the amplifier to ground to enable the output of the amplifier to swing as close to ground as possible. This will prevent the first LED from turning on prematurely. The completed circuit, including the sensor, signal conditioning, and display module, is shown in Figure II.

Adjustment Procedure: Only two simple, non-interactive adjustments are needed to set the initial offset and full-scale span. To adjust the offset, apply zero differential pressure to the sensor, then adjust R_8 for 0V at V_d (sensor output between Pin 4 and Pin 2 of the SPX). To adjust the span, apply 10psid to the sensor and adjust R_P until the 10th LED just lights.

Circuit Performance: As the pressure increases from 0 to 6psid, the green LEDs 1-6 will progressively light up. At 7psid the first yellow LED will light up, indicating that the filter should be changed. At 9 and 10psid, the red LEDs will turn on, indicating a severely clogged filter.

The maximum static error for this circuit will be within $\pm 3\%$ and the expected error over temperature extremes should be within $\pm 5\%$.

CONCLUSION

By combining these two basic components, the SPX series sensor and the NSM3914 display module, with some simple signal conditioning circuitry, one can make a reliable, cost effective pressure display. The basic design illustrated here using an SPX sensor can easily be expanded to include other sensors such as the SX and LX06xxx series.

Noise Considerations when Using Piezoresistive Pressure Sensors

By Duane Tandeske

INTRODUCTION

The one source of error found in all systems is noise. Obviously, the higher the noise, the lower the accuracy and resolution become. In some systems, such as those used for monitoring very low pressures, noise can be a significant problem. Such low-level measurement designs require a familiarity with noise, its characteristics and its sources. This application note discusses the low frequency noise that is present in a variety of Sensym's pressure sensors and transducers and comparative results are given.

GENERAL — HOW TO MEASURE NOISE

Since all electronic components generate noise, a noise measurement system was designed that has an order of magnitude less noise than the sensors to be measured. The signal-to-noise ratio (or, in this case, noise-to-noise ratio,) determine the minimum sensor noise that can be measured. The following is a list of items that have a direct effect on the measurement system.

- Power Supplies
- Amplifiers
- Filters
- Ground Loops
- Lead Lengths
- Component Values

To minimize noise from the power source, batteries were used in our test system to power the sensor and amplifiers. Since all semiconductor amplifiers also have low frequency $1/F$ noise as well as popcorn type noise, these sources represent the background noise for the ideal sensor. To minimize amplifier noise, a very low noise amplifier must be used. A general purpose amplifier could easily generate much more noise than the sensor and this noise would not be distinguishable from the sensor noise. For our test system, shown in Figure II, a low noise LT1007CH amplifier from Linear Technology Corp. was selected. (See Figure I)

Also, to minimize stray noise pick-up all lead lengths to the inputs of the amplifiers must be kept as short as possible in any noise measurement system. Because resistors also generate noise proportional to the resistor value, the resistor values must also be kept as low as practical.

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MEASUREMENTS

Noise measurements were made with the system shown in Figure II. The HP7015B recorder has a 10Hz Bandwidth with the internal filters switched out; Figure III shows the frequency response on the 5mV/cm range. The following sensors were tested and graphs of the results are shown in the accompanying figures.

LX06001G	Figure V
SCX01G	Figure VI
SX01G	Figure VII
SPX50D	Figure VIII
LX1601GB	Figure IX

Each sensor was allowed to warm up for 5 minutes and a 10 second trace was run on each. The "Base Line" noise of the amplifier is shown in Figure IV. Since the amplifier has a gain of 1000V/V, 1mV represents $1\mu\text{V}$ of noise when referred to the input.

RESULTS

The graphs for the four sensors can be misleading. At first glance, they all seem to have about the same noise voltage. However, they are quite different in signal-to-noise ratio when the sensitivity of the sensor is taken into consideration.

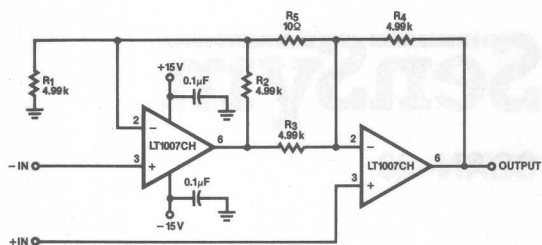
Table I compares the peak-to-peak noise voltage of each sensor and the signal-to-noise ratio for that particular sensor. The noise voltage of the sensors were independent of the pressure range for each family of unamplified sensors. This was not true, however, of the signal-conditioned transducers; since the amplifier was the major noise source, the pressure range that has the lowest amplifier gain had the least noise voltage.

CONCLUSION

These tests show that the noise generated by the sensor was very small when compared to other noise sources. However, for particularly noise-critical applications, the SX, SCX, or LX06xxx series should be the preferred sensors. Also, in applications where a small percentage of the total span is used or the pressure to be measured is very small (less than 1psi), amplifier selection and circuit layout is as important as the sensor selection.

TABLE 1
Typical DC to 10Hz Noise 0.1psi

DEVICE TYPE	V _s	SENSITIVITY (mV/psi)	NOISE VOLTAGE (P/P)	NOISE (psi)	SIGNAL-TO-NOISE (Ratio)
SX01D	12V	38	$1\mu\text{V}$	2.6×10^{-5}	90dB
SPX50D	3V	5.7	$1\mu\text{V}$	1.7×10^{-4}	75dB
SCX01DN	12V	18	$2\mu\text{V}$	1.1×10^{-4}	79dB
LX06001G	12V	33.6	$1\mu\text{V}$	2.9×10^{-5}	90dB
LX1601GB	15V	1V/psi	1mV	1×10^{-3}	60dB



- $A_v = 1000, 1\mu V = 1mV$
- POWER IS FROM $\pm 15V$ BATTERY
- ALL RESISTORS RN50D

FIGURE I
Low Noise Amplifier

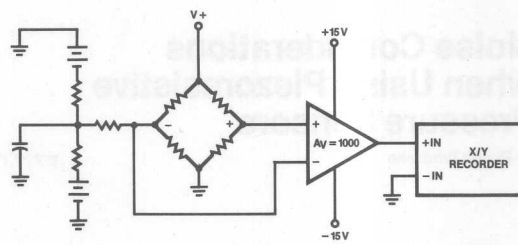


FIGURE II
Noise Test System

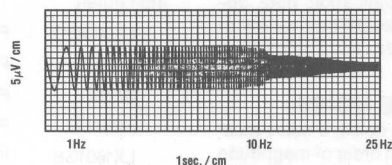


FIGURE III
x/y Recorder vs. Frequency

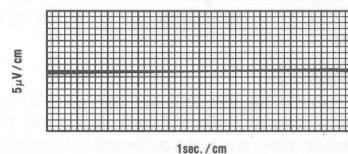


FIGURE IV
Low Noise Amplifier

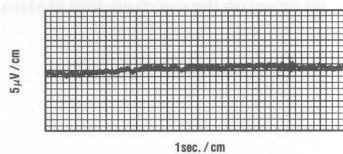


FIGURE V
LX06001G Sensor

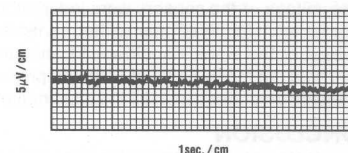


FIGURE VI
SCX01G Sensor

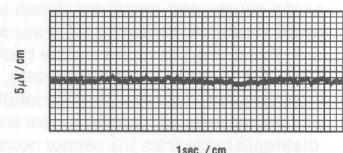


FIGURE VII
SX01D Sensor

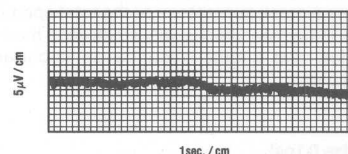


FIGURE VIII
SPX50D Sensor

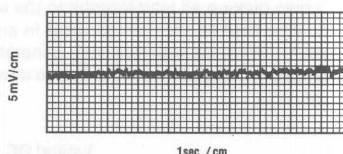


FIGURE IX
LX1601GB Transducer

Understanding Absolute Pressure Sensors

Sensym

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INTRODUCTION

Most people are typically accustomed to dealing in gage pressure, that is, pressure relative to the normal atmospheric pressure which surrounds us. As such, "absolute" pressure and absolute pressure sensors which measure pressure relative to a perfect vacuum can be somewhat confusing. Also, because zero absolute pressure (a perfect vacuum) is impossible to achieve, it is much harder to measure and calibrate absolute pressure sensors. This application note will discuss what absolute pressure is, how it is best measured and how to calibrate absolute pressure sensors.

DIFFERENTIAL (GAGE) PRESSURE

It is often easier to understand absolute pressure if we have a clear understanding of differential and gage pressure which we are generally more familiar with.

Differential pressure is the pressure difference measured between two pressure sources. This is usually expressed in pounds per square inch differential (psid). When one source is the ambient pressure, this is then called gage or relative pressure and is typically expressed in pounds per square inch gage (psig). Therefore, gage pressure is simply a special case of differential pressure with pressures measured differentially but always relative to the local ambient pressure. In the same respect, absolute pressure can also be considered a differential pressure where the measured pressure is compared to a perfect vacuum.

ABSOLUTE PRESSURE

Absolute pressure sensors are most commonly used to measure changes in barometric pressure or as altimeters. These applications require reference to a fixed pressure as they cannot be simply referenced to the surrounding ambient pressure.

Absolute pressure is defined as the pressure measured relative to a perfect vacuum. For example, 10 pounds per square inch absolute (psia) would be 10psi above a perfect vacuum. This is roughly 4.7psi below the standard atmospheric pressure at sea level of 14.7psia. 0psia is then the pressure of a perfect vacuum.*

Sensym's absolute pressure sensors are made by hermetically sealing a vacuum reference chamber on one side of the integrated circuit sensing element. (See Figure I) Pressures to be measured are then measured relative to this vacuum reference. The actual "vacuum" which is sealed into the sensor is approximately 0.0005 psia (25 millitorr). Using this near vacuum as a reference eliminates any potential thermal errors which would occur if any gas was trapped in the reference chamber as it would exert a pressure during expansion and contraction with temperature in accordance with Boyles law. One of the advantages of integrated circuit sensors is the small volume of trapped vacuum reference which, in conjunction with a reliable silicon-to-silicon hermetic seal, makes these devices time and temperature stable.

*Footnote: For illustration purposes in this note, pounds per square inch (psi) is used as the unit of pressure measure. This unit can obviously be converted to other common pressure units such as mmHg, kPa, bar, etc.. (See the attached chart for individual conversion factors.)

CALIBRATING ABSOLUTE SENSORS

To use any sensor in an absolute application, we must be able to accurately calibrate the device for offset and span. This requires understanding offset and span in terms of absolute pressure.

OFFSET VOLTAGE

The Offset voltage is defined as the sensors output at zero differential pressure. For gage sensors, this is the output with ambient pressure (0psig) applied to the sensor. As such, offset voltages are relatively easy to measure for gage sensors. However, *for an absolute device, the offset voltage is the output voltage of the sensor with a perfect vacuum (0psia) applied to the sensor.* This means that with normal atmospheric pressure applied to the absolute sensor, there will be an output voltage which corresponds to approximately +14.7psia at sea level.

Because a perfect vacuum is impossible or at least impractical to obtain, measuring the actual offset voltage for absolute sensors is not possible. At Sensym, we draw a vacuum to 1psia and then in combination with the output at full scale, use a straight line approximation to calculate the 0psia output or offset voltage. This same technique can be applied using any two pressure points provided the sensor is perfectly linear. The non-linearity induced errors will vary depending on the pressure points used but can easily be limited to less than $\pm 0.1\%$ if the 10% full scale output (FSO) and 90% FSO reference points are used for the straight line approximation of 0psia.

SPAN

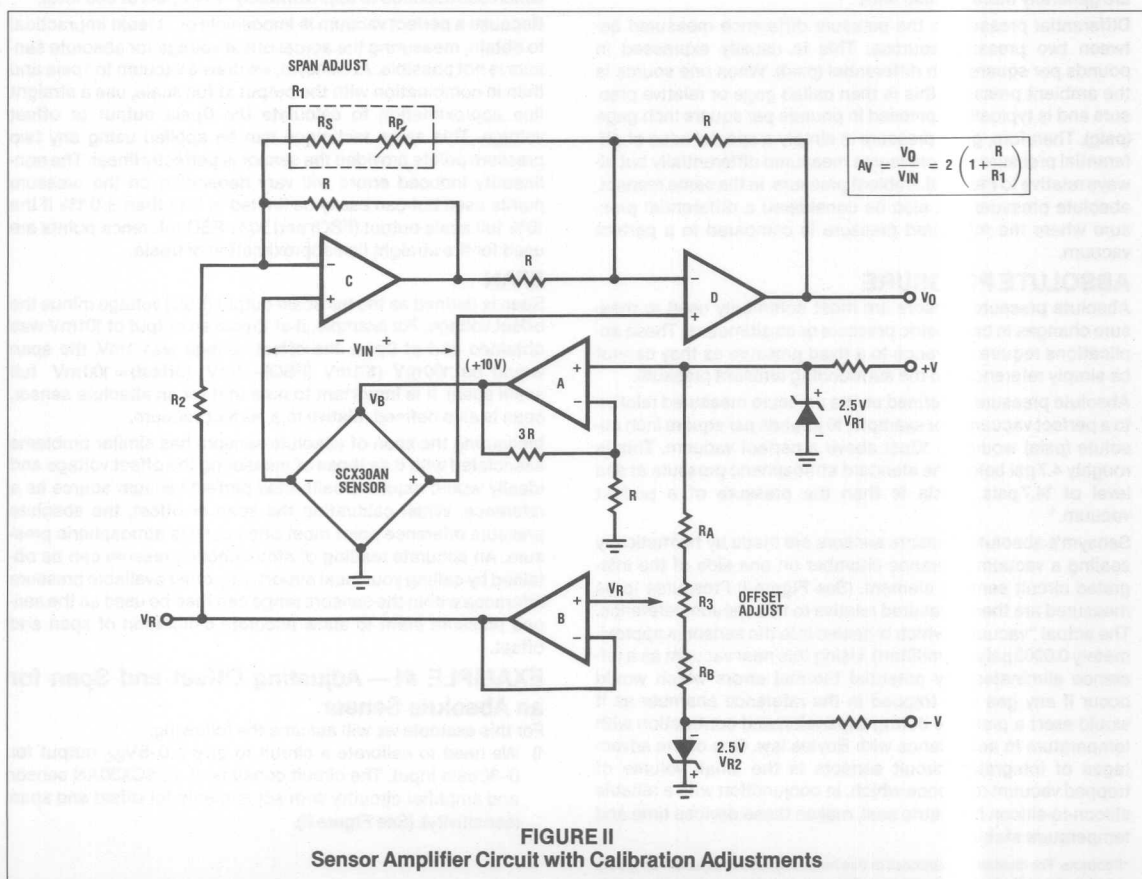
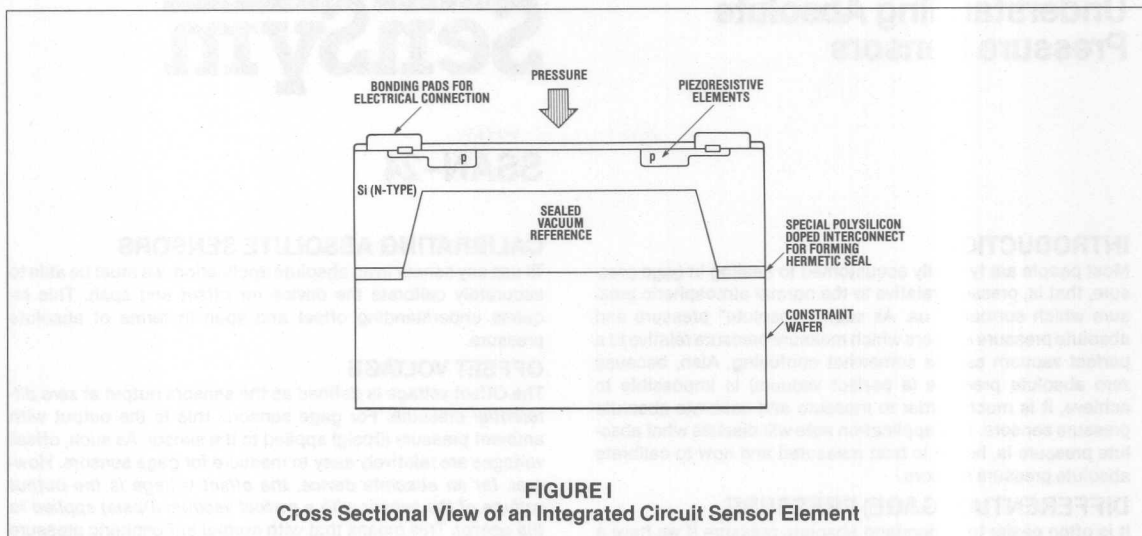
Span is defined as the full scale output (FSO) voltage minus the offset voltage. For example, if at 15psia an output of 101mV was obtained and at 0psia the offset voltage was 1mV, the span would be 100mV (101mV (FSO) - 1mV (offset) = 100mV full scale span). It is important to note that for an absolute sensor, span is also defined relative to a perfect vacuum.

Measuring the span of absolute sensors has similar problems associated with it as those of measuring the offset voltage and ideally would require a calibrated perfect vacuum source as a reference. When calibrating the span or offset, the absolute pressure reference point most often used is atmospheric pressure. An accurate reading of atmospheric pressure can be obtained by calling your local airport. Any other available pressure reference within the sensors range can then be used as the second pressure point to allow accurate calibration of span and offset.

EXAMPLE #1 — Adjusting Offset and Span for an Absolute Sensor

For this example we will assume the following:

- 1) We need to calibrate a circuit to give a 0-5V_{DC} output for 0-30psia input. The circuit consists of an SCX30AN sensor and amplifier circuitry with adjustments for offset and span (sensitivity). (See Figure II).



- 2) The only available pressure source/standard is a +15.000psig gage reference pressure. Therefore, the local airport must be relied upon for the absolute barometric reference point. We will assume that they give a reading of 755mmHg for the current barometric pressure. (This is equal to 14.60psi, as $755\text{mmHg} \times 0.019337\text{psi/mmHg} = 14.60\text{psi}$.) Mathematically, it can easily be shown that using these two reference pressure points (barometric pressure and a gage reference), one can properly adjust for offset and span. The basic output equation at a given voltage for this sensor is given by:

$$V_{OUT} = (S \times P) + V_{OS}$$

where: V_{OUT} is the output voltage in volts
 S is the sensitivity of the sensor in volts/PSI
 P is the applied pressure, and
 V_{OS} is the offset error of the sensor.

Determining sensitivity using these two pressure points gives us two equations as follows:

At atmospheric pressure,

$$V_{01} = [S \times (P_{atmos})] + V_{OS}$$

and at 15psig,

$$V_{02} = [S \times (P_{atmos} + 15\text{psig})] + V_{OS}$$

Assuming S is constant then:

$$V_{02} - V_{01} = S \times (15\text{psig}) \text{ or,}$$

$$S = \frac{V_{02} - V_{01}}{15} \text{ volts/PSI} \quad (1)$$

To solve for sensitivity since we have one equation, we need to know both V_{02} and V_{01} .

Once sensitivity is known offset can also be determined as:

$$V_{OS} = V_{01} - S \cdot P_{atmos} \quad (2)$$

where: V_{OS} = Offset error of the sensor
 V_{01} = Measured output at P_{atmos}
 S = Calculated sensitivity for each sensor
 P_{atmos} = Barometric pressure which is given

An example of a calibration procedure for our sensor circuit is given below:

- 1) Apply power and allow the circuit to warm-up. Measure the output of the circuit with ambient (barometric) pressure applied. Let's assume that the output of the circuit is 2.458 volts. We can calculate that the "ideal" reading at 14.60psia (ambient barometric pressure) is 2.433 volts ($14.60\text{psi} / 30.00\text{psi} \times 5.00\text{volts} = 2.433\text{volts}$). However, given only this one measurement point, we cannot determine how much of this error is due to zero pressure (offset) error and how much is due to ambient pressure (sensitivity) error.

- 2) Next, apply the in-house +15.00psig reference pressure and measure the output. For this example, we'll assume an output reading of 4.972 volts. Using Equation (1), we can now determine the actual sensitivity of our sensor as follows:

$$S = \frac{V_{02} - V_{01}}{15} = \frac{4.972\text{V} - 2.458\text{V}}{15\text{psi}} = 0.168\text{V/psi}$$

Then, using Equation (2), the offset error is calculated to be:

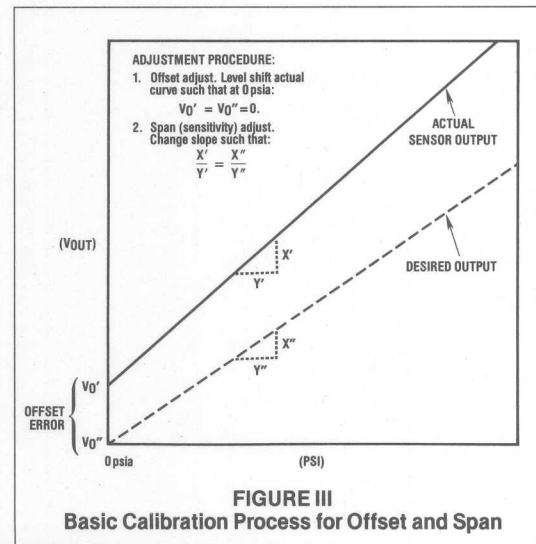
$$V_{OS} = V_{01} - S \cdot P_{atmos} = 2.458\text{V} - [0.168\text{V/psi} (14.60\text{psia})] = 0.011\text{volts}$$

- 3) We can now adjust the offset and span as follows: Since the circuit shown in Figure II has the advantage of virtually independent trims, we can adjust offset and then span in this example. For circuits with more interactive effects it may be better to first adjust span, then offset. (i.e. Rotate the curve, then level shift. See Figure III for a simple graphic depiction of the adjust procedure.) In either case, one should go back and check the first adjustment after completing the second.

For best results, offset should be set at the lowest reference pressure. In this example, offset is then set at barometric pressure (14.60psia). The offset adjust should be adjusted such that the output at barometric pressure (V_{01}) is 2.447 volts. This is the original reading of 2.458 volts minus the calculated offset error of 0.011 volts.

Once the offset is adjusted, span is set using either the highest reference pressure available or where maximum accuracy is required. The +15psig reference point is used here as an example. Span adjustment should be made to set the output at +15psig (V_{02}) to 4.933 volts. This is 29.60psi times the ideal sensitivity of 0.1667 volts per psi ($5.00\text{volts}/30\text{psi} = 0.1667\text{V/psi}$).

To complete the calibration process, we can now check and fine tune, if necessary, the offset reading.



CONCLUSION

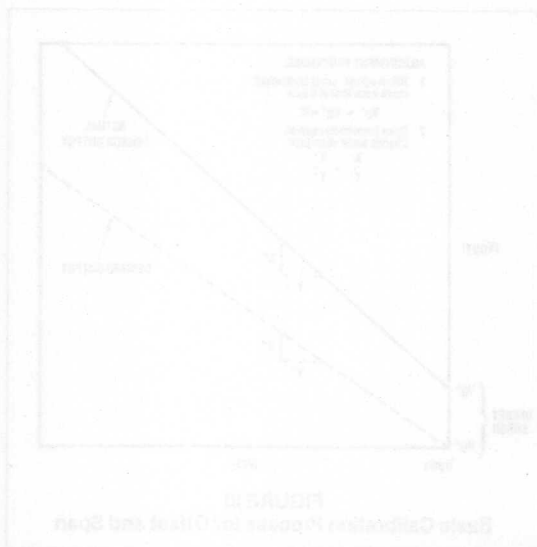
Although absolute pressure sensors are perhaps not as well understood or easily calibrated as gage pressure devices, by using barometric pressure as a reference in conjunction with any other reference point, gage or absolute, absolute pressure devices can be accurately calibrated.

PRESSURE UNIT CONVERSION CONSTANTS

(Most Commonly Used — Per International Conventions)

	PSI ⁽¹⁾	In. H ₂ O ⁽²⁾	In. Hg ⁽³⁾	kPa	millibar	cm H ₂ O ⁽⁴⁾	mm Hg ⁽⁵⁾
PSI ⁽¹⁾	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
In. H ₂ O ⁽²⁾	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In. Hg ⁽³⁾	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
kPa	0.14504	4.0147	0.2953	1.000	20.000	20.2973	7.5006
millibar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H ₂ O ⁽⁴⁾	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg ⁽⁵⁾	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Notes: 1. PSI — pounds per square inch 2. at 39°F 3. at 32°F 4. at 4°C 5. at 0°C 6. 1 Torr = 1 mmHg



Installation Techniques for the SCX Series Sensors

By Duane Tandeske

INTRODUCTION

The SCX series sensors are high precision calibrated and temperature compensated pressure sensors. However, to achieve optimum performance, they must be properly installed. This application note will discuss recommended package mounting, electrical connection and pressure connecting techniques to achieve optimum performance.

MOUNTING

When mounting any sensor, the two most important considerations are the physical package location and mounting technique. The location of the sensor is very important from a reliability standpoint. For example, if a sensor is connected to a compressed air line that contains water and oil vapor from the compressor, the sensor should never be installed at the lowest point in the line as any water that has condensed in the line would flow into the sensor and be trapped. However, if the sensor is mounted at the highest point in the line, the liquid would be forced to flow uphill in order to get into the sensor. This results in less condensation at the sensor which generally increases overall reliability. For installations where it is impossible to mount the sensor at the highest point, a loop or filter should be put in the line. A number of companies make filters which can be used to protect the sensors from moisture.

They include:

Del Tech Engineering
New Castle, Delaware
(302) 328-1345

Balston Filter Products
Lexington, Massachusetts
(800) 343-4048

The mechanical mounting of the package can also induce stress and effect the sensors' performance, particularly in low pressure differential measurements. As shown in Figure I the actual integrated circuit sensor chip is mounted in Sensym's standard chip carrier (an SX sensor package) and this carrier package is then sealed into the overall SCX package with RTV seals. These soft mounts help absorb stress and minimize sensitivity of the sensor to stresses on the outer package. However, squeezing or bending the outer package can still cause offset voltage errors equivalent to 0.1 to 0.2 inches of water column change in high sensitivity parts, such as the SCX01DN. Therefore, in precision low pressure (less than 1psi) applications, the package should be mounted in such a way as to minimize external package stresses. For PC board mounting it is fairly easy to limit the package stresses with proper mounting. The simplest recommended PC board mounting technique is to use "xmas tree" clips as fasteners. This technique is illustrated in Figure II. The xmas tree clip has a lower insertion force than removal force, with a ratio as high as four to one. By clamping to the inside of the 0.16 inch mounting hole of the SCX package, this clip secures the SCX device to the board and gives a minimum package stress even over temperature. We recommend a Fastex

Fastex
Des Plaines, Illinois
Part No. 354-156001-00-2099
(708) 299-2222

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If the sensor is not mounted on a panel or PC board but on a pipe or manifold, 6-32 screws can be used to secure the package. Care must however be taken not to over-tighten the screws as this will torque the package and can induce offset errors.

The package can also be stressed through the pressure ports when rigid or semi-rigid tubing is used for pressure connection. The differential configuration is the most susceptible to package stress from the pressure ports as the two tubes can generate substantial stresses when pushed together or pulled apart. Therefore, if rigid tubing is used, spacers should be used to keep the two tubes parallel and lined up with the pressure ports.

ELECTRICAL CONNECTIONS

Connectors

The leads on the SCX series sensors are 0.025 inch square leads on 0.1 inch centers. This is a standard configuration in the industry and a variety of mating connectors are available, including:

Samtec
New Albany, Indiana
6 pin right angle
Part No. SSW-106-02-TSRA
(812) 944-6733

Methodie
Rolling Meadows, Illinois
6 pin right angle
Part No. 9000-106-302
(312) 392-3500

The recommended mounting technique using these connectors is shown in Figure II, and dimensions for PC board layout are shown in Figure III. We generally recommend the use of these connectors as it allows the devices to be easily inserted and removed without inducing any stress related errors. Using these connectors in combination with the xmas tree clips for PC board mounting provides reliable and stress-free mounting for optimum overall performance.

Soldering

The leads can also be bent 90° and soldered into the PC board. During the bending operation, the leads should be clamped next to the housing to insure that no stresses are transferred to the internal compensation ceramic or plastic package.

PRESSURE CONNECTORS

All SCX series sensors have two 0.190 inch outside diameter pressure ports for applying the pressure media (see SCX Datasheet). In low pressure applications (15psi and below), silicon tubing is recommended for pressure connection as it is easy to work with and quite flexible so package stresses are minimized. For 30 and 100psi ranges, stronger Tygon tubing with Tyton clamps around the tubing is recommended. Over 100psi, 0.25 inch outside diameter and 0.035 wall thickness Tyton tubing and Tyton snapper hose clamps are recommended. Snapper clamps are available in acetal copolymer for general purpose applications and in heat stabilized glass fiber compound for high temperature applications (see Figure III). For more information contact:

Tyton Corporation
Milwaukee, Wisconsin
Snapper — SNP-1
(414) 355-1130

CONCLUSION

The SCX series sensor will provide a high precision solution for pressure applications in the 1 to 100psi pressure range. However, to get the maximum reliability and performance from the sensor, proper installation techniques must be followed.

ORDERING INFORMATION

Sensym is stocking and will sell small quantities of the following SCX accessory parts:

Samtec 6 Pin Right Angle Socket Order
Sensym Part Number — SCXCNCCT. (Available in 100 Piece Lots Only.)

Tyton (SNP-1) Clamp Order Sensym Part Number SCXSNPI. (Available in 100 Piece Lots Only.)

Fastex Christmas Tree Clips. Order Sensym Part Number SCXCLIP. (Available in 200 piece Lots Only.)

For OEM quantities contact the various manufacturers directly.

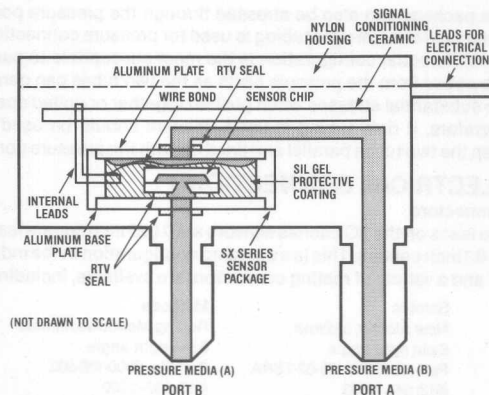


FIGURE I
SCX Physical Construction Diagram (Cutaway View)

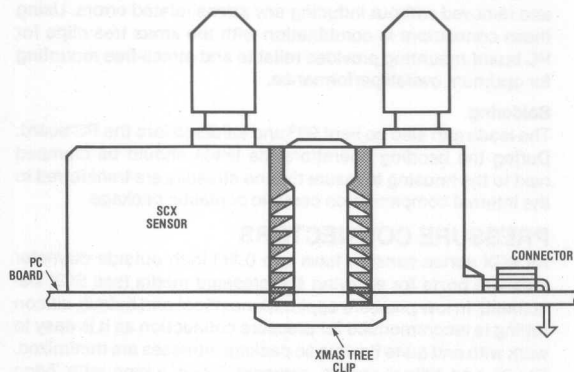


FIGURE II
Recommended PC Board Mounting Technique for the SCX Sensor

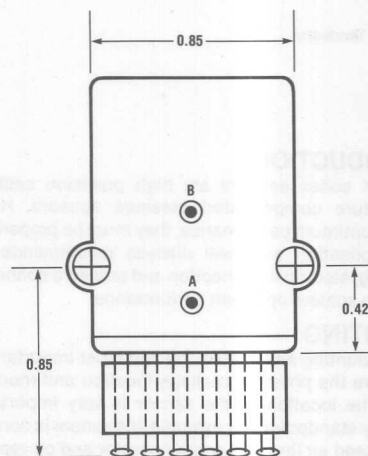
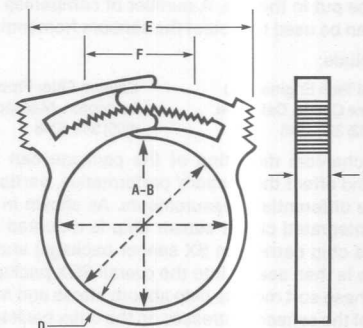


FIGURE III
SCX Package and Samtec
SSW-106-02-TSRA Connector



Stock Number	Unit of Measure	Min. Dia.	Max. Dia.	A	B	C	D	E	F	Number of Teeth
SNP-1	In.	.228	.256	.148	.040	.451	.320	12		
	mm.	5.8	6.5	3.8	1.0	11.5	8.1	12		
SNP-1.5	In.	.307	.342	.146	.054	.587	.410	12		
	mm.	7.8	8.7	3.7	1.4	14.9	10.4	12		
SNP-2	In.	.351	.394	.231	.067	.672	.472	12		
	mm.	8.9	10.0	5.9	1.7	17.1	12.0	12		

FIGURE IV
Tyton Snappers—Clamps Pressure Hose
onto Port

Pressure Switch

By Duane Tandeske

INTRODUCTION

Pressure switches are used in a wide variety of applications. For example, a gage sensor can be used to indicate the presence of a work piece on a vacuum chuck or holder, or in a multiple switch point system to maintain a constant tank pressure. The use of pressure switches is widespread and virtually unlimited. The most prevalent and lowest cost pressure switches, at least for single-set point applications, are mechanical switches. The key features of these mechanical switches are their low cost, small size, and ability to switch heavy loads (amps and volts). These mechanical switches will therefore continue as the best alternative for many applications. However, in those applications where reliability is a major concern, the IC sensor-based switch can offer a distinct advantage. One of the critical problems with mechanical switches is wear, which causes set point shifts with time and fatigue or failure of moving parts which results in a limited number of pressure cycles. Since the semiconductor sensor has no moving parts, this problem is eliminated.

This application note will give some basic switch configurations and the design details for low cost, reliable, semiconductor sensor pressure switches.

BASIC ELECTRONIC SWITCH

In the simplest terms, a pressure switch provides an ON-OFF signal, depending upon the pressure level. A variety of outputs are possible. For semiconductor systems one of the most common is a high/low logic level to interface with digital circuits.

The basic element for all of these semiconductor-based switches, however, is a comparator or operational amplifier with positive feedback to provide hysteresis. This hysteresis, the amount of which can be set for each application requirement, provides a clean, usable switch by eliminating any jitter around the switch point. Examples are presented here which show the use of this concept for both single- and multi-set point switches.

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Design Example I: A Single-Set Point Switch

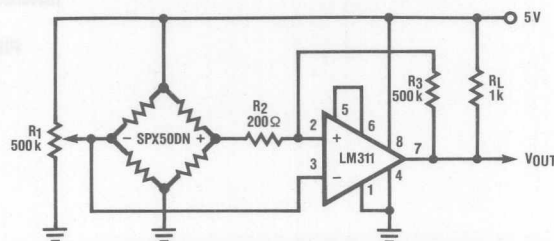
Automatic die bonders and pick-and-place equipment that use a vacuum chuck or holder need a pressure switch to indicate the presence of a die or work piece. When a die is present, the holes in the vacuum chuck are blocked and a vacuum is generated at the chuck. When no die is present, the holes in the chuck are vented to atmosphere and almost no vacuum is measured at the chuck.

Assuming a pressure near atmospheric pressure for "no die" and a vacuum of -6 psig for "a die", we can set a switch point of -4 psig. Here, a high output (above -4 psi) represents "no die" and a low output (below -4 psig) represents "a die".

To make this switch easily usable in a standard system configuration, it was designed to meet the following criteria:

1. Inexpensive
2. Operate from $5V_{DC}$
3. $\pm 10\%$ accuracy $25^{\circ}C \pm 15^{\circ}C$
4. Drive standard TTL logic

As shown in Figure I, the basic switch is made up of an SPX50DN and LM311 comparator. Given the 10% accuracy and limited temperature range required here, span compensation is not necessary as the -2350 ppm/ $^{\circ}C$ span TC specification for the SPX50D over $30^{\circ}C$ is only a 3.5% error and the combined total error is still less than 10%. For this single switch circuit, resistors R_2 and R_3 set the amount of hysteresis in the system. To eliminate jitter around the switch point and aberrant readings, the hysteresis should be set such that it is just larger than the maximum noise in the system.



BASIC SWITCH

FIGURE I

The actual amount of hysteresis for this example circuit can be more easily calculated by referencing the equivalent switch circuit in Figure II.

For the circuit in Figure II, it can be shown that:

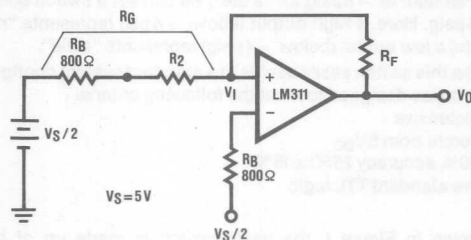
When V_O is 0V,

$$V_I = \frac{V_S}{2} \left[\frac{R_F}{R_F + R_G} \right] \text{ and:}$$

When V_O is $+V_S$,

$$V_I = \frac{V_S}{2} \left[\frac{1 + 2 \frac{R_G}{R_F}}{1 + \frac{R_G}{R_F}} \right]$$

Using the resistor values given in Figure I for this example, when V_O is 0V, V_I is 2.495V and when V_O is $+V_S$ (5V) V_I is 2.505. This yields hysteresis of 10mV.



EQUIVALENT CIRCUIT

FIGURE II

ADJUST PROCEDURE

For the circuit in Figure I, the set point is adjusted by R_1 . Before adjusting the set point, disconnect one end of resistor R_3 to remove the hysteresis. Next, apply the desired set point pressure and adjust R_1 until V_{OUT} just changes state. Now, reconnect R_3 and check that the output changes state just above and below the set point.

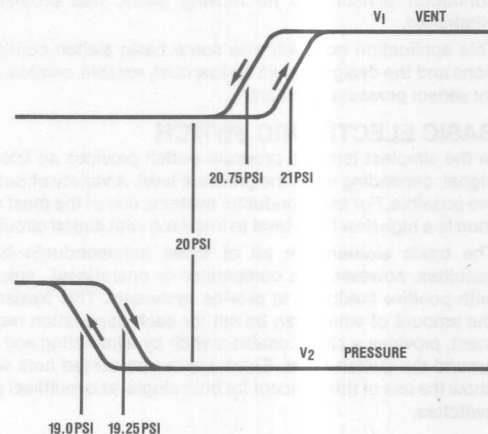
Design Example II: A Multiple-Set Point Switch

Another advantage a linear pressure sensor offers over most mechanical switches is the ability to easily do multiple switch points. Although any number of switch points can be set anywhere within the pressure sensor's operating pressure range, the most commonly used switch is the dual-set point switch. The following example will illustrate the principle of a dual-set point switch using a low cost pressure sensor. To illustrate this multiple-set point switch, we will assume that a system needs to be designed that will maintain a pressure vessel at a precise working pressure. If the pressure rises due to temperature or altitude, the system will bleed off the excess pressure, and if the pressure decreases due to low temperature or leakage, the system will increase the pressure by connecting the tank to a pressure source until proper working pressure is restored.

We will assume that the system will have to meet the following specifications:

- Control pressure = 20 psig
- Operate from 12V_{DC}
- $\pm 2\%$ accuracy over a temperature range of 0°C to +70°C

The controller will consist of a SCX30DN to measure the pressure, a 10V reference voltage to power the sensor, a voltage divider, and two comparators and valve drivers to control the vent and pressure valves. (See Figure IV.)



TRANSFER CHARACTERISTICS

FIGURE III

DESIGN CONSIDERATIONS

The sensitivity of the SCX30DN is 2.5mV/psi when operated at 10V. This output will, however, have to be amplified to drive the comparators. As shown in Figure IV, amplifiers A₂ and A₃ make up an instrumentation amplifier with a gain of 50. Therefore, the signal at the output of the amplifier is now 125mV/psi. The gain equation for this amplifier stage is given by:

$$\frac{V_O}{V_{IN}} = 2 \left[1 + \frac{10k}{R_0} \right]$$

To keep the controller from "hunting", the two comparators have been designed with 0.25psi (31mV) of hysteresis. Figure III shows the transfer characteristics of each comparator.

As seen from the transfer curves, if the pressure is between 19 and 21psi both valves are closed, but if the pressure decreases below 19psi V₂ is opened until the pressure reaches 19.25psi. Likewise, if the pressure increases above 21psi V₁ opens and the tank is vented to 20.75psi.

ADJUSTMENT PROCEDURE

There is only one adjustment in this circuit. Pot R₆ adjusts the offset or switching point of V₂ (pressure switch), the vent switch point is fixed 1.75psi above V₂. To adjust the offset, connect the negative lead of a DVM to test point A and the positive lead of the meter to test point B. With 19psi applied to the sensor, adjust R₆ for a reading of +16mV on the meter, this will set the first switch point at 19psi.

CONCLUSION

Low cost controllers can be designed using IC sensors such as the SPX50DN and SCX30DN. Given the small number of components required and simple adjustment procedures, this semiconductor sensor-based switch is now a cost effective solution for many control applications.

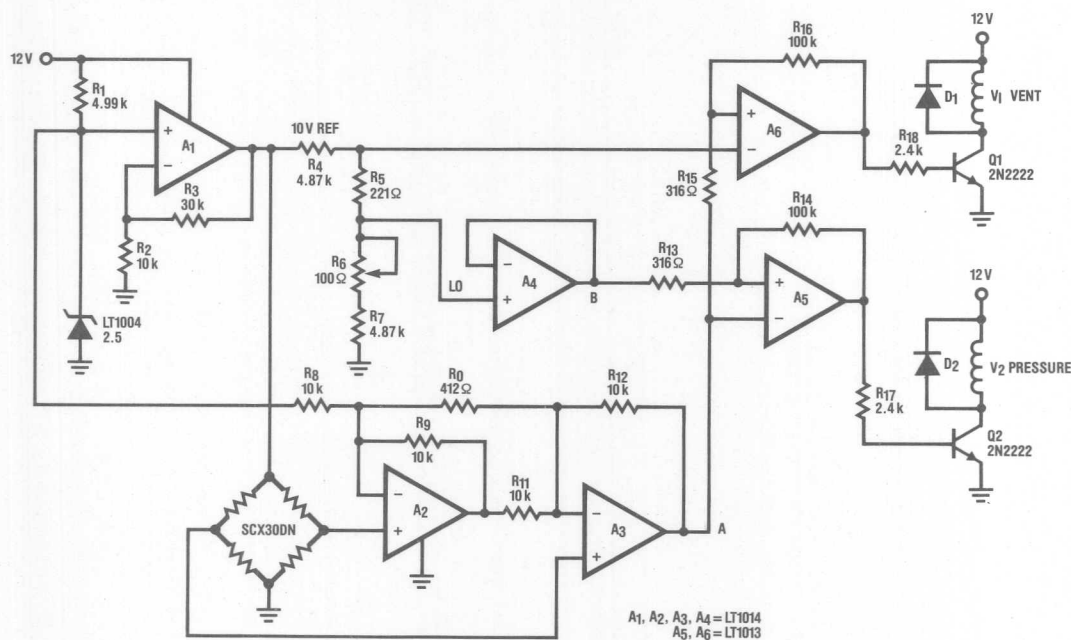


FIGURE IV

PRESSURE UNIT CONVERSION CONSTANTS

(Most Commonly Used — Per International Conventions)

	PSI(1)	In. H ₂ O(2)	In. Hg(3)	K Pascal	milli Bar	cm H ₂ O(4)	mm Hg(5)
PSI(1)	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
In. H ₂ O(2)	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In. Hg(3)	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
K Pascal	0.14504	4.0147	0.2953	1.000	20.000	20.2973	7.5006
milli Bar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H ₂ O(4)	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg(5)	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Notes: 1. PSI — pounds per square inch

2. at 39°F

3. at 32°F

4. at 4°C

5. at 0°C

Conversion from Constant Current to Constant Voltage Excitation

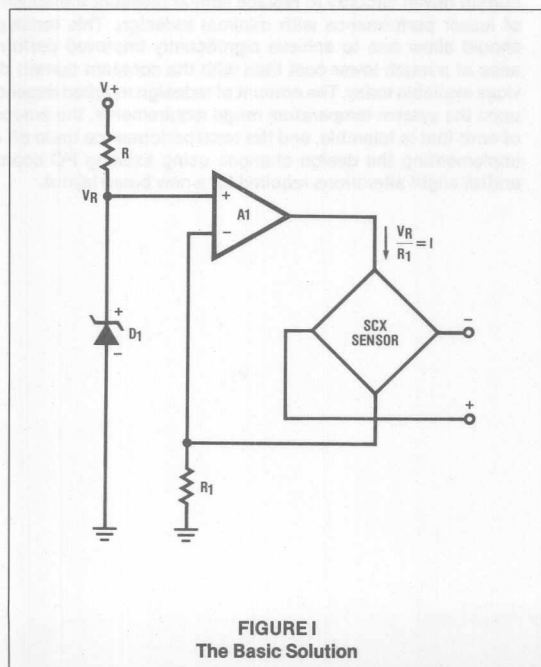
By Scott Weatherwax

INTRODUCTION

To achieve good span compensation many silicon IC pressure sensor manufacturers require their sensors to be driven by a constant-current-source. The major disadvantage of current driven sensors is that to achieve precision performance, the span compensation scheme required for each sensor is unique to that sensor. If, for some reason a sensor needs to be replaced the resistors used in the compensation must also be replaced. And, if you want to upgrade your system to a truly compensated, higher performance sensor you must either upgrade to a high quality, more expensive sensor driven by a constant-current-source, or rework your entire circuitry to accommodate a more common, and generally lower cost, type of sensor driven by a constant-voltage-source. This application note will discuss alternative circuits and trade offs in changing a sensor driven by a current excitation to operate with Sensym's new high performance, low cost, constant voltage driven SCX series pressure sensor.

THE BASIC SOLUTION

Most constant-current-sources are designed with a single operational amplifier configuration as shown in Figure I.



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SSAN-27

It is interesting to note that no one uses a true constant-current-source to drive their sensor. To achieve a constant current source a temperature independent voltage reference (V_R) and a temperature independent resistor (R_1) and a temperature independent op amp are required to produce a true constant current which is then forced through the sensor. By simply changing the value of R_1 (or V_R) different currents can be produced to meet the needed specifications. Unfortunately, this type of design causes some additional problem over temperature. Although the sensor is temperature compensated, the op-amp and the voltage reference are not compensated. For temperature changes, therefore, their error must be added into the overall error caused by the sensor itself. These "hidden" errors are often neglected when a constant current drive sensors error budget is calculated.

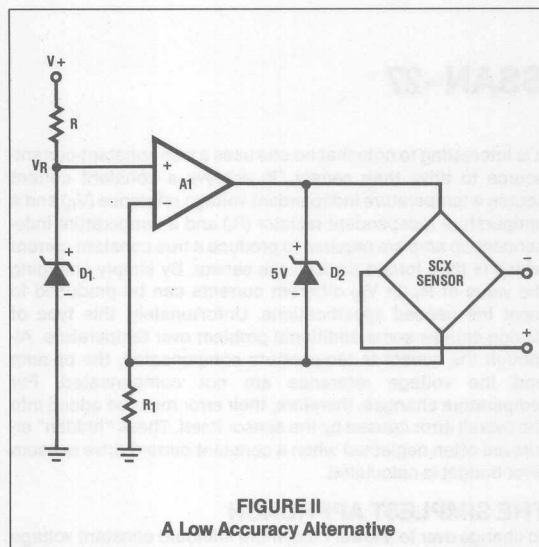
THE SIMPLEST APPROACH

To change over to a lower cost, more standard constant voltage type device in a design which already has a constant current source sensor, one obvious solution is to simply replace the constant-current driven sensor with the constant voltage sensor. Although any constant voltage sensor, such as Sensym's SCX sensor will operate when driven by a constant current, this circuit will have a serious problem as it is highly temperature sensitive. For example, if the temperature remains relatively constant ($25^\circ\text{C} \pm 10^\circ\text{C}$) the full scale span output could vary by as much as 7%. but as the temperature changes say from 0°C to 70°C , even if the temperature coefficient of the voltage reference is zero, the resistance of the sensor changes, causing the voltage across the sensor to vary. Because the output of the sensor, in this case the SCX, is ratiometric to the voltage across it, this voltage variation will drastically effect the span of the sensor. The span error could then be as high as 25% of the full scale output over a temperature range of 0°C to 70°C . Although an error of 25% over temperature is intolerable in most systems, there are better solutions available.

A LOW ACCURACY ALTERNATIVE

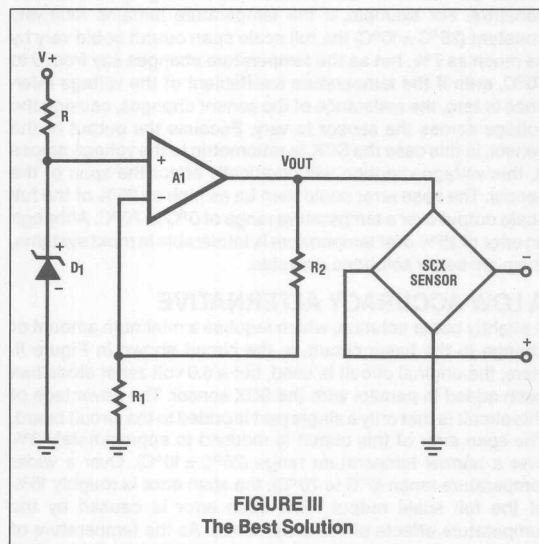
A slightly better solution, which requires a minimum amount of change to the basic circuit, is the circuit shown in Figure II. Here, the original circuit is used, but a 5.0 volt zener diode has been added in parallel with the SCX sensor. The advantage of this circuit is that only a single part is added to the circuit board. The span error of this circuit is reduced to approximately 3% over a narrow temperature range ($25^\circ\text{C} \pm 10^\circ\text{C}$). Over a wider temperature range (0°C to 70°C), the span error is roughly 15% of the full scale output. This span error is caused by the temperature effects of the zener diode. As the temperature of the zener changes, the voltage it supplies to the sensor

changes, thus causing the output of the sensor to change. Since, for many systems a 15% span error is still unacceptable, a true high accuracy constant voltage circuit is shown in the next section.



THE BEST SOLUTION

The best solution, shown in Figure III requires a minimal redesign of the basic configuration while offering the best performance.



The only circuit changes required to the basic configuration are (assuming the PC board art is not readily changeable) to replace the present sensor with a fixed resistor R_2 , and connect the SCX sensor from the output of the op amp to the circuit ground. In this manner, the amplifier is now configured as a non-inverting amplifier with a gain of

$$A_v \left(1 + \frac{R_2}{R_1}\right)$$

This means the output of the amplifier will be

$$V_{OUT} = V_R \times \left(1 + \frac{R_2}{R_1}\right)$$

volts and this powers the SCX sensor at that voltage. Now the temperature shift problem associated with the first two solutions is eliminated. In this configuration, the voltage needed to power the sensor is not as dependent upon the zener as were the previous circuits. Although the circuit performance will be slightly effected by the ratio of resistors R_1 and R_2 over temperature, by using 1% metal film resistors (± 100 ppm/ $^{\circ}\text{C}$ or better), this error will be minimal. If a good reference is used, such as the LT1009CZ (Linear Technology Corp.) the total system span error is now reduced to about 1% over the temperature range of 0°C to 70°C , and significantly less over the temperature range of $25^{\circ}\text{C} \pm 10^{\circ}\text{C}$.

CONCLUSION

The SCX series pressure sensor can be used with constant current driven circuitry to replace similar pressure transducers of lesser performance with minimal redesign. This redesign should allow one to achieve significantly improved performance at a much lower cost than with the constant current devices available today. The amount of redesign required depends upon the system temperature range requirements, the amount of error that is tolerable, and the cost/performance trade off of implementing the design changes using existing PC boards and/or slight alterations required for a new board layout.

0V to 5V Sensor Amplifier which Swings to Ground

By Roland Lee

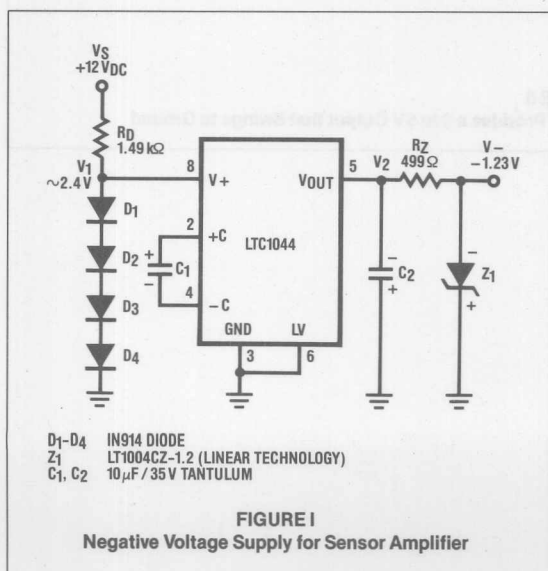
INTRODUCTION

As more control systems become computerized, there is an increased need for a pressure signal output that is compatible with digital circuits. A common input requirement of many low-cost A/D converters is 0 to 5V. Unfortunately, the voltage swing of many signal conditioning amplifiers can only come within 100mV of ground when using a single power supply. A true 0 to 5V output circuit would then require a negative power supply to allow the amplifier output to swing to ground. However, the addition of a negative power supply is often too costly, or cumbersome for any given design. Therefore, a simple, low-cost solution is needed to provide a negative voltage reference for a signal conditioning amplifier such that the amplifier can swing to ground.

This application note will discuss a pressure sensor signal conditioning circuit with a voltage converter to provide a true 0 to 5V output that swings to ground when using only a single +12V supply.

CIRCUIT DESCRIPTION

As shown in Figure I, by using an LTC1044 (Linear Technology) voltage converter, a stable and low-cost negative supply voltage can be generated from a single +12V power supply. Here, the diode string delivers approximately 2.4V to V_1 and pin 8 on the LTC1044. By using a switched capacitor technique, capacitor C_1 will charge to voltage V_1 , and the total charge on C_1 will be $Q_1 = C_1 V_1$. As the internal switches change position, part of Q_1 is transferred to C_2 . By continuously charging C_2 , a -2.3 voltage supply is created at the negative node of C_2 .



Sensym

SSAN-28

The negative voltage at V_2 will vary due to the diode potentials changing at V_1 and to the charge changing on C_2 . So, in order to minimize this noise which would directly effect V_{REF} and V_{OUT} in Figure II, a micropower zener Z_1 , is used to provide a stable and low noise negative voltage supply at V_- . For the resistor values shown, the noise is less than 1mV peak-to-peak at V_- as long as the current requirement of the amplifier is less than 2.4mA. Additional current can be provided by increasing V_1 on the voltage converter or by reducing the resistance of R_Z .

The bandgap reference, Z_2 provides a stable and low noise positive voltage reference for the sensor excitation voltage, V_E , in Figure II. The voltage at Z_2 is amplified to 10V for the sensor excitation voltage, so voltage variations and line noise on the +12V line will not cause sensor output errors. Similarly, the voltage at V_{REF} is held stable at the positive node by Z_2 as well as on the negative node by Z_1 .

As shown in Figure II, the two op amp instrumentation amplifier in combination with the voltage converter shown in Figure I will provide a true 0 to 5V output that will swing to ground. The output equation is given as follows:

$$V_{OUT} = V_{IN} \cdot 2 \left(1 + \frac{R}{R_P + R_S} \right) + V_{REF}$$

Where: R_0 adjusts V_{REF} so that V_{OUT} equals 0.0 volts at zero pressure and R_P adjusts the full scale output such that at full pressure V_{OUT} equals 5.0 volts.

This amplifier configuration provides good common-mode rejection, high impedance inputs that do not load the sensor outputs, and a simple adjustment procedure. For the best results, use 2% tolerance thick film resistor arrays for closely matching resistor values and low temperature coefficients. Also, use precision op amps with low offset voltage drift, and low noise characteristics. The power supply should be bypassed by C_3 to reduce line noise and voltage transients, while C_4 should be used to roll off high frequency circuit noise.

ADJUSTMENT PROCEDURE

- Vent the sensor to atmosphere and adjust R_0 until $V_{OUT} = 0.00V$.
- Apply full scale pressure to sensor and adjust R_P until $V_{OUT} = 5.00V$.
- Repeat (A) and (B) as necessary.

DESIGN EXAMPLE

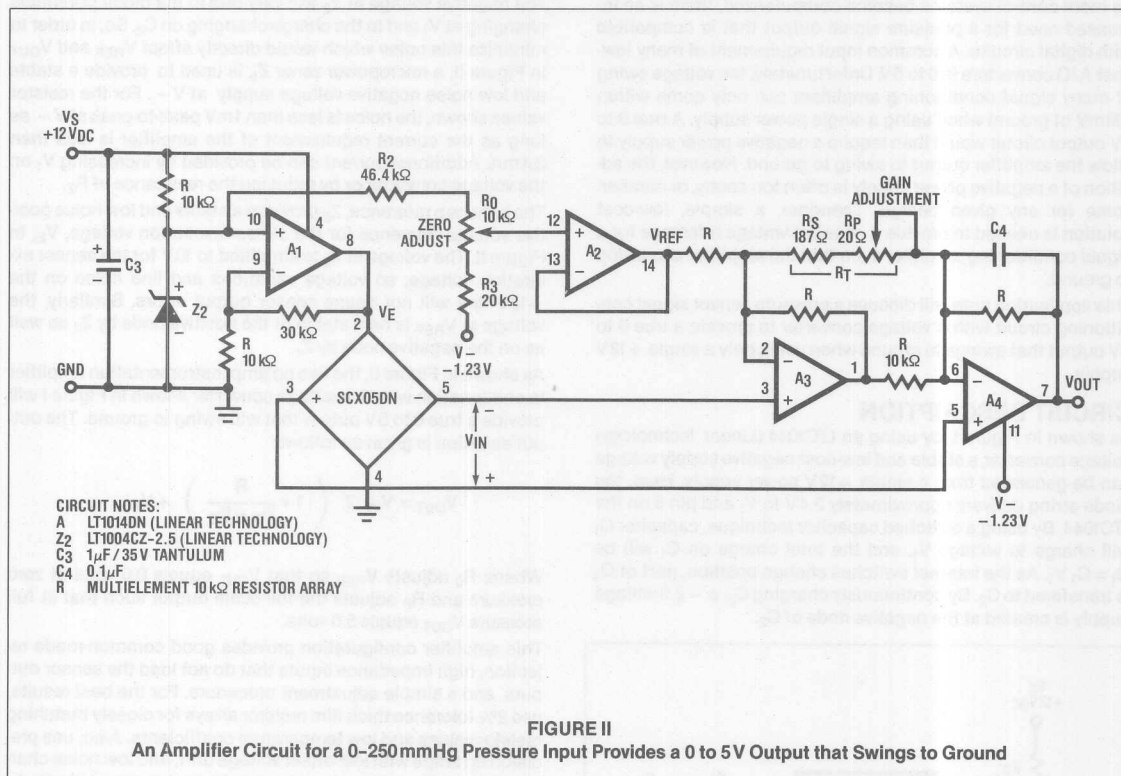
Consider a medical respirator where the air to a patient is controlled between 0 to 250mmHg. A single conditioning amplifier is necessary to provide a 0 to 5V input signal to an A/D converter.

By using an SCX05DN and the amplifier circuits in Figures I and II, a simple interface circuit can be provided. The only calculation necessary is for the gain resistor R_T . As given in the SCX datasheet, the SCX05DN will output 60mV at $V_E = 12V_{DC}$ and with 5 psi (258.6 mmHg) applied. So, with $V_E = 10V_{DC}$ and at 250mmHg full pressure, the SCX05DN will output 48.3mV. The signal gain necessary for a full-scale output of 5V is $A_V = 103V/V$. Using the gain equation, if $R = 10k\Omega$, then $R_T = 197\Omega$. To allow for sensor span variations, let R_S equal a 187 Ω 1% metal film resistor and R_P equal a 20 Ω cermet pot. The zero pressure output can be adjusted $\pm 230mV$ by letting R_2 equal 46.4k Ω , R_3

equal 20k Ω and R_O equal a 10k Ω cermet pot. Using the simple adjustment procedure shown previously, this circuit will provide a true 0-5V $_{DC}$ output for 0-250mmHg. This output can then be fed directly to a number of A/D converters.

CONCLUSION

By using a voltage converter and a two op amp instrumentation amplifier, a simple 0 to 5V output that swings to ground can be provided. This output is particularly useful for interface with many A/D converters that require a 0 to 5V input range.



A Solid-State Barometer

By Scott Weatherwax

SenSym

SSAN-29

INTRODUCTION

By using a new semiconductor pressure sensor, a low cost yet very reliable barometer can be designed. This application note will discuss the use of the new SCX15ANC absolute¹ pressure sensor to design two different types of low cost, solid state barometers. The first example uses a 15V power supply and provides an analog output voltage which is proportional to the barometric pressure. This output voltage can easily be scaled to represent mBar, mmHg, or inHg. The second example, provides the design of a portable digital barometer powered by a 9V battery, such as might be used by a backpacker. The signal output in this example is a 3½ digit LCD display.

EXAMPLE 1 — Analog Voltage Output Scaled in mBar

CIRCUIT DESCRIPTION

Figure I shows the basic circuit needed to construct a barometer with an output voltage which is directly proportional to the barometric pressure. Referring to Figure I, amplifier A₁ is used to provide a 10V regulated supply voltage to the sensor. In this manner, the circuit becomes independent of variations due to the 15V power supply. Altitude correction² (or offset adjustment) is provided by amplifier A₂, in conjunction with potentiometer R₃. Amplifiers A₃ and A₄ are connected as an instrumentation amplifier and provide gain to the output of the sensor. A detailed description of this particular instrumentation amplifier configuration can be found in Sensym application notes SSAN-17 and SSAN-18. However, the gain equation is given by

$$\frac{V_{OUT}}{V_{IN}} = A_O = 2 \left(1 + \frac{R_T}{R_1} \right) \quad (1)$$

DESIGN CALCULATIONS

Barometer Scaled in mBar

Using the circuit in Figure I, the output voltage can be scaled such that this voltage will correspond directly to barometric pressure in mBar (1psi = 68.947 mBar). For example, at 1013.8 mBar (sea level), we would like to have the output equal to 10.138V (representing 1013.8mBar). Correspondingly, at 1310.3 mBar we would like to have the output equal to 13.103V (representing 1310.3 mBar). In this manner, a 10mV change is equal to a 1 mBar pressure change. Therefore, a change of 296.5 mBar will result in a change of 2.965V. Using the gain equation we can calculate the gain resistor, R_T, that is required. From the SCX-15ANC data sheet we note that the output span for 15psi is equal to 90mV when operating from a 12V supply. This equates to 0.5mV per volt per psi. Thus at 10V and a change of 296.5 mBar (4.3psi) the output of the sensor will change 21.5mV. Because it is required that 296.5 mBar pressure change provide an output voltage change of 2.965V, the gain required is 137.9V/V. Solving for the gain resistor, R_T, in equation 1, using R₁ equal to 10kΩ, R_T is found to be 147Ω.

To allow for circuit tolerances and to provide the ability to precisely adjust the gain, a fixed 137Ω resistor and a multiturn 20Ω potentiometer are used for R_T. Table 1 tabulates the values for the two resistors (R_S, R_G) used in the design for the most common pressure units.

Note 1: If you are unfamiliar with absolute pressure sensors we recommend reading Sensym's application note SSAN-24, "Understanding Absolute Pressure Sensors." This will clear up many possible questions with regard to the use of absolute sensors and provide some basic understanding of the Solid-State Barometer.

Note 2: The altitude correction scheme used in this example assumes the user will not ever be below sea level.

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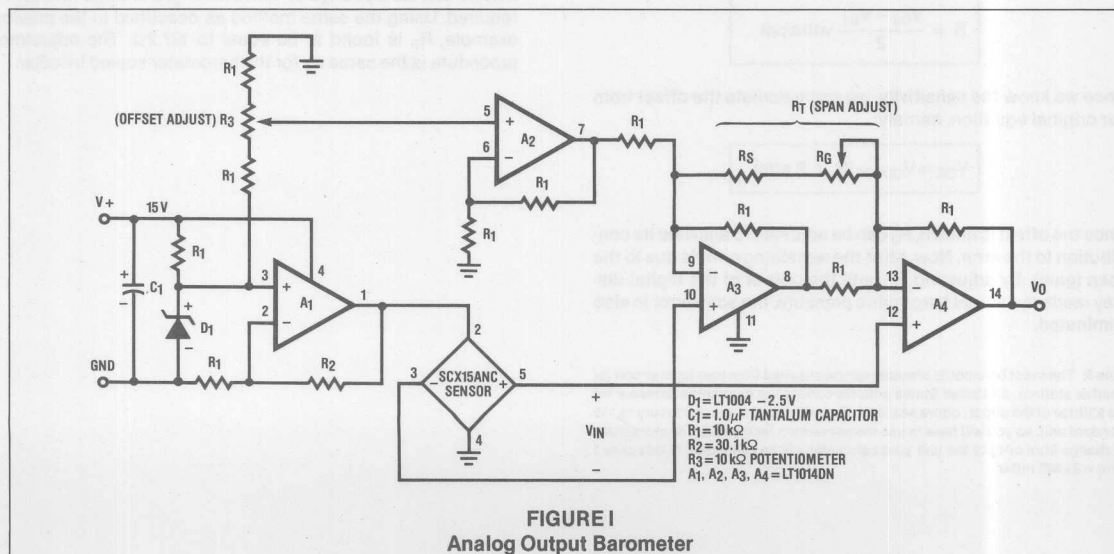


Table 1
Resistor Values R_S and R_G for Analog Output Barometers

Unit	Gain	Nominal Resistor Value	R_S	R_G
mBar	138 V/V	147 Ω	137 Ω	20 Ω
mmHg	103 V/V	197 Ω	174 Ω	50 Ω
inHg	41 V/V	517 Ω	464 Ω	100 Ω
inH ₂ O	55 V/V	375 Ω	348 Ω	50 Ω
kPascal	138 V/V	147 Ω	137 Ω	20 Ω

CALIBRATION

There are two methods to calibrate the barometer. One procedure assumes that you do not have a pressure source other than the atmospheric pressure³, and the other adjustment procedure assumes that you do have a second pressure source. To better understand the adjustment procedure, in either case, a brief mathematical explanation is in order, before the adjustment procedures are outlined.

The output voltage of the sensor, at a given supply voltage, is given by:

$$V_{OUT} = (S \times P) + V_{OS}$$

where:

V_{OUT} is the output voltage in mV

S is the sensitivity of the sensor in mV/psi

P is the applied pressure, and

V_{OS} is the offset voltage of the sensor in mV.

The sensitivity can be determined by using two known pressures since it results in two equations and two unknowns (V_{OS} , S) as follows:

at atmospheric pressure,

$$V_{O1} = [S \times (P_{atm})] + V_{OS}$$

Now, if an additional precisely known pressure, say 2 psig is applied, then

$$V_{O2} = [S \times (P_{atm} + 2 \text{ psig})] + V_{OS}$$

Since S does not change as a function of applied pressure, then

$$V_{O2} - V_{O1} = S \times 2 \text{ psi or}$$

$$S = \frac{V_{O2} - V_{O1}}{2} \text{ volts/psi}$$

Once we know the sensitivity, we can calculate the offset from our original equation, namely:

$$V_{OS} = V_{OUT} - (S \times P_{atm})$$

Once the offset is known, R_3 can be adjusted to alleviate its contribution to the error. Now, all of the remaining error is due to the span (gain). By adjusting R_T until the output of the digital display reads the actual barometric pressure, the span error is also eliminated.

Note 3: The exact barometric pressure can be obtained from your local airport (or weather station). All United States airports correct the barometric pressure for the altitude of the airport above sea level. They also use inches of mercury as the standard unit, so you will have to use the conversion factor which is appropriate to change from inHg to the unit your barometer will be calibrated; in this case 1 inHg = 33.865 mBar.

ADJUSTMENT PROCEDURE ONE

When an additional pressure source is available, you will be able to easily adjust both the offset voltage and gain as described above. The adjustment procedure is as follows:

- Turn the barometer on, and allow it to warm up for at least 10 minutes and then record the digital read out at the end of this period.
- Call the local airport (or weather station) and obtain the actual barometric pressure.
- Apply the known second pressure source and record the output.
- Use the mathematical model above to calculate the offset (and hence the span) using the two pressure points from steps (a) and (c).
- First, adjust the span potentiometer to alleviate its contribution to the error, and then adjust the offset until the output of the digital display matches the actual barometric pressure obtained in (b).

PROCEDURE TWO

If you do not have access to another known pressure source other than ambient (barometric) pressure your adjustment procedure will be less precise. When your barometer is working, you will have no way of knowing what the source of your error is; offset or span. Here, the best method of adjustment is as follows:

- Calculate the value of R_T and use the closest nominal fixed gain resistor, R_T , without a gain potentiometer.
- Now simply adjust the offset potentiometer, R_3 , to agree with the actual barometric pressure.

Without adjusting precisely for span an error of less than 3% can be expected. For normal barometer use, where we are only interested in relative change in pressure, this will not be critical.

mmHg BAROMETER

In a similar fashion as described above, the output can be scaled to mmHg (1psi = 51.714 mmHg). The same circuit can be used, with a simple recalculation of the resistor value of R_T so that our output will be scaled to represent mmHg and not mBar. For the preceding example, our output range would have been from 5.689V (568.87 mmHg) to 9.826V (982.59 mmHg). This means that for a change of 413.73 mmHg, a change of 4.137V is required. Using the same method as described in the previous example, R_T is found to be equal to 197.2 Ω . The adjustment procedure is the same as for the barometer scaled in mBar.

CONCLUSION

Many types of barometers can be constructed with the SCX-15ANC and some simple amplifier circuitry. The direct voltage readout barometer is a good lab design where the barometric pressure occasionally needs to be verified. If the barometric pressure needs to be obtained outside of the lab area, the portable barometer constructed in the second example is an excellent choice. In either case, a low cost, highly reliable, barometer can be constructed which will yield excellent results.

PRESSURE UNIT CONVERSION CONSTANTS

(Most Commonly Used — Per International Conventions)

	PSI ⁽¹⁾	in. H ₂ O ⁽²⁾	in. Hg ⁽³⁾	kPascal	mili Bar	cm H ₂ O ⁽⁴⁾	mm Hg ⁽⁵⁾
PSI ⁽¹⁾	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
in. H ₂ O ⁽²⁾	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
in. Hg ⁽³⁾	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
kPascal	0.14504	4.0147	0.2953	1.000	10.000	10.1973	7.5006
millibar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H ₂ O ⁽⁴⁾	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg ⁽⁵⁾	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Notes:

1. PSI — pounds per square inch 2. at 39°F 3. at 32°F 4. at 4°C 5. at 0°C

ALTITUDE — PRESSURE — TEMPERATURE

ALTITUDE (Feet)	PRESSURE			TEMPERATURE	
	inHg	mmHg	PSI	°C	°F
–1,000	31.02	787.9	15.25	17.0	62.6
–500	30.47	773.8	14.94	16.0	60.8
0	29.921	760.0	14.70	15.0	59.0
500	29.38	746.4	14.43	14.0	57.2
1,000	28.86	732.9	14.18	13.0	55.4
1,500	28.33	719.7	13.90	12.0	53.6
2,000	27.82	706.6	13.67	11.0	51.8
2,500	27.31	693.8	13.41	10.0	50.0
3,000	26.81	681.1	13.19	9.1	48.4
3,500	26.32	668.6	12.92	8.1	46.6
4,000	25.84	656.3	12.70	7.1	44.8
4,500	25.36	644.2	12.45	6.1	43.0
5,000	24.89	632.3	12.23	5.1	41.2
5,500	24.43	620.6	12.00	4.1	39.4
6,000	23.98	609.0	11.77	3.1	37.6
6,500	23.53	597.6	11.56	2.1	35.8
7,000	23.09	586.4	11.34	1.1	34.0
7,500	22.65	575.3	11.12	0.1	32.2
8,000	22.22	564.4	10.90	–0.8	30.67
8,500	21.80	553.7	10.70	–1.8	28.8
9,000	21.38	543.2	10.50	–2.8	27.0
9,500	20.98	532.8	10.30	–3.8	25.2

ALTITUDE (Feet)	PRESSURE			TEMPERATURE	
	inHg	mmHg	PSI	°C	°F
10,000	20.58	522.6	10.10	–4.8	23.4
10,500	20.18	512.5	9.91	–5.8	21.6
11,000	19.79	502.6	9.73	–6.8	19.8
11,500	19.40	492.8	9.53	–7.8	18.0
12,000	19.03	483.3	9.35	–8.8	16.2
12,500	18.65	473.8	9.15	–9.8	14.4
13,000	18.29	464.5	8.97	–10.8	12.6
13,500	17.93	455.4	8.81	–11.7	10.9
14,000	17.57	446.4	8.63	–12.7	9.1
14,500	17.22	437.5	8.46	–13.7	7.3
15,000	16.88	428.8	8.28	–14.7	5.5
15,500	16.54	420.2	8.13	–15.7	3.7
16,000	16.21	411.8	7.96	–16.7	1.9
16,500	15.89	403.5	7.81	–17.7	0.1
17,000	15.56	395.3	7.64	–18.7	–1.7
17,500	15.25	387.3	7.49	–19.7	–3.5
18,000	14.94	379.4	7.34	–20.7	–5.3
18,500	14.63	371.7	7.19	–21.7	–7.1
19,000	14.33	364.0	7.04	–22.6	–8.7
19,500	14.04	356.5	6.90	–23.6	–10.5
20,000	13.75	349.1	6.75	–24.6	–12.3
20,500	13.46	341.9	6.61	–25.6	–14.1
21,000	13.18	334.7	6.48	–26.6	–15.9

Simple, Low-Cost 4-20 mA Pressure Transmitter

By Roland Lee



SSAN-30

INTRODUCTION

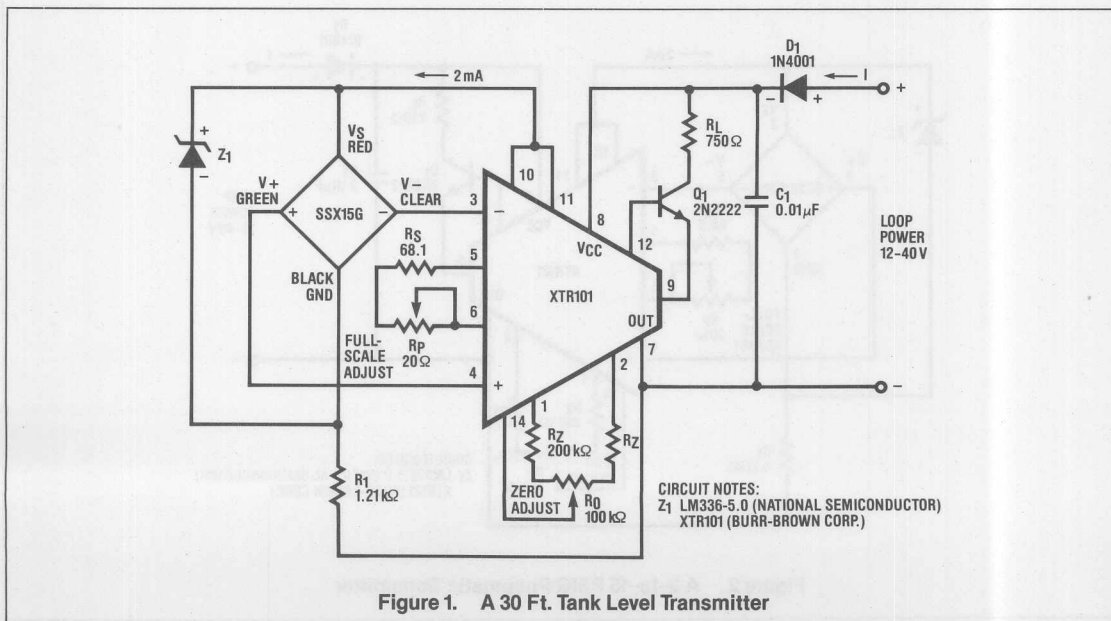
The two wire 4-20mA transmission loop is one of the most popular output signals for pressure sensing devices in industrial applications. The use of current as a transmission signal provides a low impedance transmission path which is less susceptible to induced noise pickup. This also eliminates the concern of IR drop along the line, which makes the signal relatively independent of line resistance and line length. Best of all, there is no ambiguity between a zero pressure reading and an open circuit because at least 4mA of current is always flowing through the circuit.

The main disadvantage of 4-20mA pressure transmitters has been their high costs which have continued even though low-cost semiconductor pressure sensors are available. However, now by using a new low cost precision integrated circuit sensor in combination with a single IC, a simple low-cost pressure transmitter can be realized. Sensym's new SCX or SSX series sensors can be used with the XTR101 (Burr Brown Corporation) to make a high accuracy, reliable, pressure transmitter. The temperature compensated SCX or SSX sensor utilizes hybrid technology and laser trimmed resistors to achieve zero offsets of less than $\pm 1\text{mV}$ and span calibrations within 1% FSO. The XTR101 is a monolithic device especially designed to convert the low-level signal from a sensor to the desired current output. It features dual matched 1mA current sources as well as full scale adjustment nodes. This application note will discuss how to construct a simple and low-cost 4-20mA transmitter using the sensor and XTR101.

CIRCUIT DESCRIPTION

By using the built-in features of the SCX sensor and the XTR101, a simple pressure transmitter can be made as shown in Figure 1. The XTR101 will provide two one milliamp current sources for sensor excitation if the bias voltage between the V_{CC} and OUT pins is between 12 and 40 volts. The SCX is a constant voltage device, and driving the sensor with constant current will increase its output errors over temperature. Therefore, a 5.0 voltage reference is placed in parallel with the sensor to maintain a constant sensor voltage. The SCX sensor has a nominal input impedance of $4\text{ k}\Omega$, thus requiring 1.25 mA with a 5 volt sensor supply. This circuit leaves $750\mu\text{A}$ to bias the voltage reference which is within the operating range of the LM336-5.0.

On the XTR101, the common-mode voltage of the signal inputs (pins 3 and 4) from the sensor must be between 4 and 6 volts above the voltage at the OUT pin (pin 7). This requirement can be easily satisfied by inserting a 1.21k Ω resistor in series with the sensor. This connection raises the common-mode voltage of the sensor outputs to 4.9V above the negative supply. The 2.4V is in addition, to the normal common-mode voltage of the sensor output of 2.5 volts from the outputs being one-half of the 5 volt sensor supply voltage. These connections enable the sensor outputs to be typically 4.9V higher than pin 7 and near the middle of the common-mode input range of the XTR101.



SPAN ADJUSTMENT

The XTR101 provides a full-scale adjust by connecting a resistor between pins 5 and 6. The gain resistor can be easily calculated from the following equation.

$$R_T = \frac{40}{\frac{16 \text{ mA}}{\text{Span}} - 0.016}$$

Where: R_T is in ohms, and span is the sensor output at full-scale minus the offset voltage in millivolts. To allow for calibration of the full-scale output, R_T consists of a fixed-value resistor (R_S) and an adjustment pot (R_P).

ZERO ADJUSTMENT

The transmitter can be adjusted for offset errors by using a pot (R_0) and two resistors (R_Z) connected to the XTR101. This adjustment comes in contact with the internal instrumentation amplifier, and for every $100 \mu\text{V}$ of adjustment the transmitter will drift an additional $\pm 0.3 \mu\text{V}/^\circ\text{C}$. Therefore, it is recommended that low offset devices be used to minimize possible transmitter errors. Although this adjustment method induces a slight error into the transmitter, an offset adjustment connected directly to the sensor output is likely to induce larger temperature errors by causing an imbalance in the sensor resistors and compensation networks.

OTHER CONSIDERATIONS

Transmitter accuracy is increased by using an external transistor to reduce the heat dissipated by the XTR101. The transistor is connected in parallel with an internal transistor where the load current will be shared. A 750Ω ($1/4$ to $1/2$ watt) resistor in series with the collector is recommended for systems that have a power supply greater than 24 V .

Lead lengths on the circuit board should be kept as short as possible to reduce noise and parasitic resistance. It is especially important to minimize the lead lengths for the high impedance signal input and the offset adjustment nodes on the converter.

By placing a $0.01 \mu\text{F}$ capacitor and a diode near the XTR101 package, the circuit is protected from voltage transients and reverse polarity of the power supply.

DESIGN EXAMPLES

Example I: A 30 Ft. Tank Level Indicator

A 30 ft process tank holds a solution with a specific gravity of 0.95. A pressure sensor is located near the bottom of tank to monitor the solution height. The pressure at the bottom of the full tank can be calculated as follows:

$$P(\text{fs}) = \frac{(0.95) 30 \text{ ft} \times 12 \text{ in/ft}}{27.68 \text{ in/PSI}}$$

$$P(\text{fs}) = 12.36 \text{ PSI}$$

The SSX15G is used for this application for the convenience of a threaded mount and stainless steel isolation. From the SSX15G datasheet, the device will have an output of 90 mV at 15 PSI with a 12 V power supply. The SSX15G is ratiometric so with a 12.36 PSI input and a 5 V supply, the sensor will output 30.9 mV . The gain resistor can be found by using the gain equation where R_T is calculated to equal 79.7Ω . To allow a five percent span adjustment range, let R_S equal a 68.1Ω resistor and R_P a 20Ω pot. A zero adjustment of $\pm 280 \mu\text{A}$ is provided by letting R_Z equal $200 \text{ k}\Omega$ and R_0 equal a $100 \text{ k}\Omega$ pot. The completed circuit is shown in Figure 1.

ADJUSTMENT PROCEDURE

- Vent the sensor to atmosphere and adjust R_0 so that I_{OUT} equals 4.00 mA .
- At a full pressure of 12.36 PSI , adjust R_P so that I_{OUT} equals 20.00 mA .
- Repeat (A) and (B) as necessary.

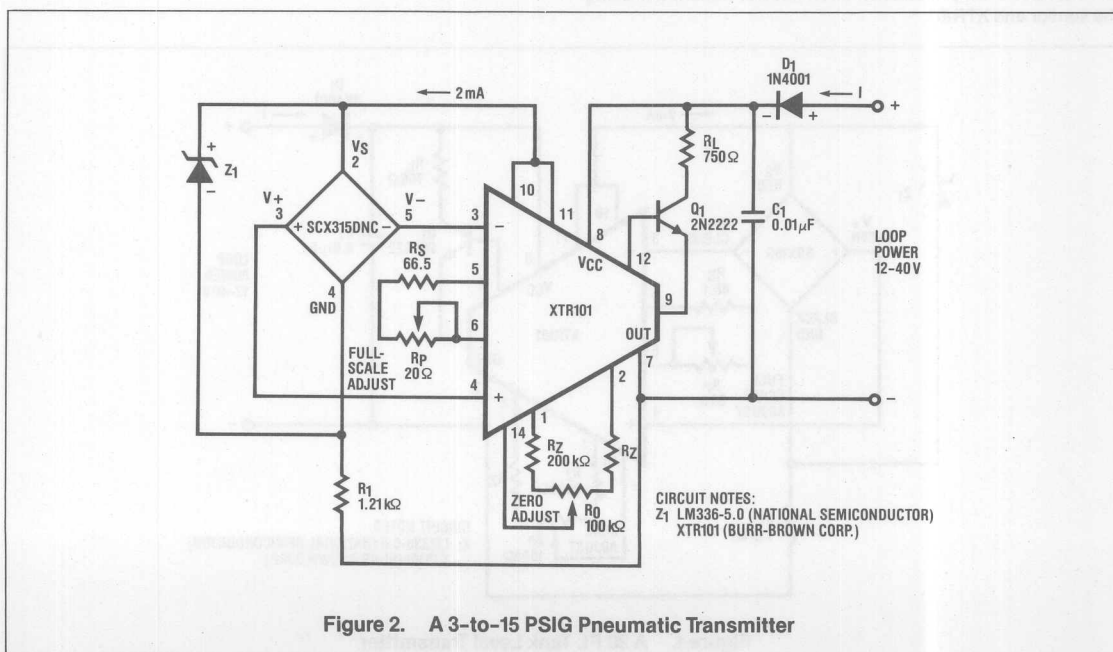


Figure 2. A 3-to-15 PSIG Pneumatic Transmitter

Example II: A 3-5 PSI Pneumatic Transmitter

The SCX315DNC has been especially calibrated for the 3-to-15 PSI range such that the sensor output at 3 PSI is equal to 0 volts. Therefore, as shown in Figure 2, no additional components are needed to offset the 3 PSI pressure signal as with other pressure devices. This pressure transmitter can still use the same simple adjust procedure as in the first example to measure the 3-to-15 PSI pressure range used in pneumatic controls. From the SCX315DNC datasheet, the sensor will have an offset of 0V at 3 PSI, and at 15 PSI the sensor will output 72mV with a 12 V_{DC} supply. The gain resistor can be found by calculating the span with 5 volts of excitation and substituting the output into the gain equation. R_T is calculated to equal 77 Ω . To allow for a five percent span adjustment let R_S equal a 66.5 Ω resistor and R_P a 20 Ω pot. By having R_Z equal 200k Ω and with R_0 a 100k Ω pot, the offset current can be adjusted $\pm 280 \mu A$.

ADJUSTMENT PROCEDURE

- Apply 3 PSI to the sensor and adjust R_0 such that I_{OUT} is equal to 4.00 mA.
- Apply 15 PSI and adjust R_P until I_{OUT} is equal to 20.00 mA.
- Repeat (A) and (B) as necessary.

Example III: A 0-100 PSI Cooling System

An SSX100G is used to monitor a cooling system that has a operating range of 0-to-100 PSI. From the SSX100G datasheet, the sensor will output 100mV with 100 PSI applied and a 12 V_{DC} excitation voltage. With a 5V excitation the SSX100G will have a full-scale output of 41.7 mV. R_T can be found by the gain equation to equal 109 Ω . Allowing for $\pm 5\%$ adjustment let R_S equal a 100 Ω resistor and R_P a 20 Ω pot. By letting R_Z equal a 200k Ω resistor and R_0 equal a 100k Ω pot, the offset current can be adjusted by $\pm 200 \mu A$.

ADJUSTMENT PROCEDURE

- Vent the sensor, and adjust R_0 until I_{OUT} equals 4.00 mA.
- Apply 100 PSIG to the sensor, and adjust R_P so that I_{OUT} equals 20.00 mA.
- Repeat (A) and (B) if necessary.

CONCLUSION

By combining the SCX or SSX compensated sensors with the XTR101, a simple and low-cost 4-20mA pressure transmitter can be designed. This design requires a minimum of additional components and provides a cost effective solution to many industrial pressure sensing applications. For further information please contact the Applications Department at Sensym.

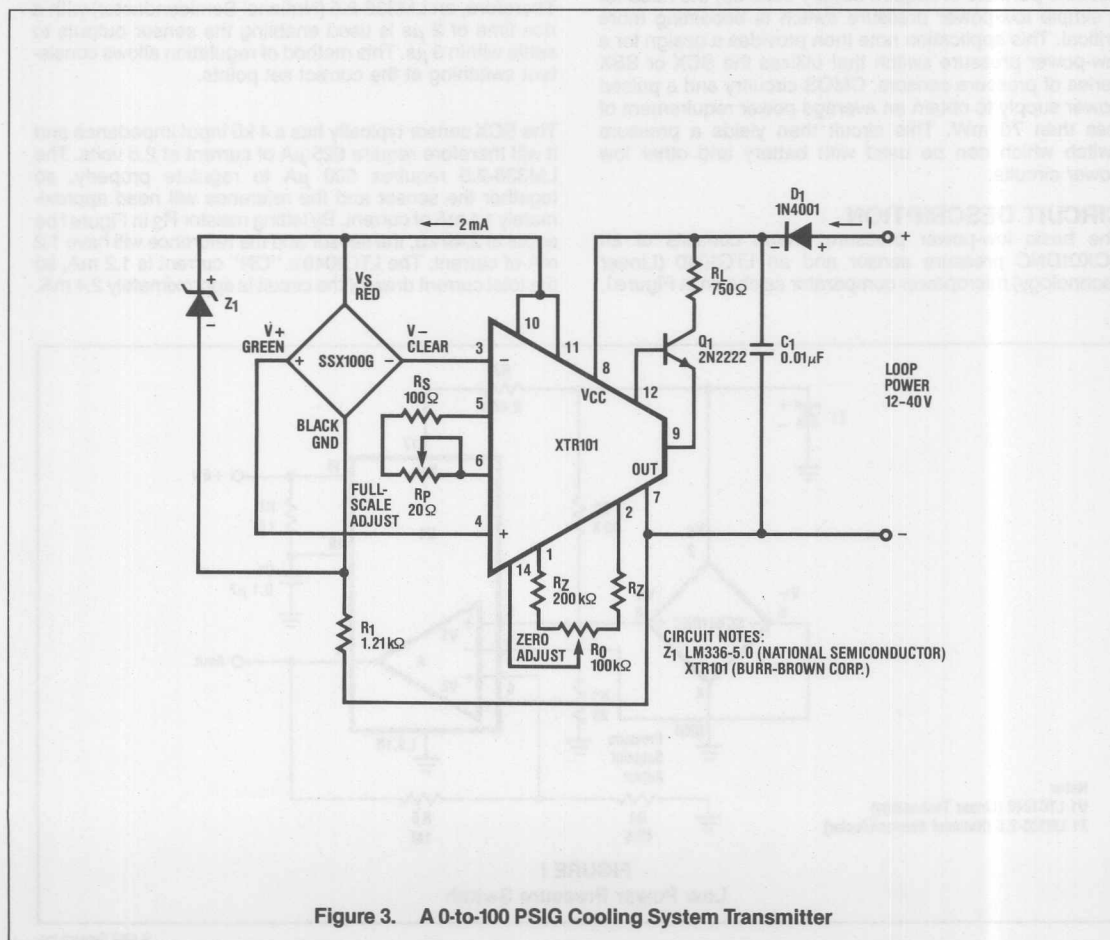


Figure 3. A 0-to-100 PSIG Cooling System Transmitter

Micropower Pressure Switch

By Roland Lee

INTRODUCTION

One of the most common applications of a pressure sensor is found in its use as a pressure switch to set a simple on-off control signal. Although there are many techniques for making a pressure switch, a new approach is needed to achieve low-power pressure switches and controllers, if one is to preserve DC accuracy, low-cost and simplicity.

A simple pressure switch can easily be made by connecting a pressure sensor to a comparator and setting the trip point. However, such a circuit will generally require a supply current that consumes too much power for battery powered applications. As more and more applications become portable or require battery back-up, the need for a simple low-power pressure switch is becoming more critical. This application note then provides a design for a low-power pressure switch that utilizes the SCX or SSX series of pressure sensors, CMOS circuitry and a pulsed power supply to obtain an average power requirement of less than 70 mW. This circuit then yields a pressure switch which can be used with battery and other low power circuits.

CIRCUIT DESCRIPTION

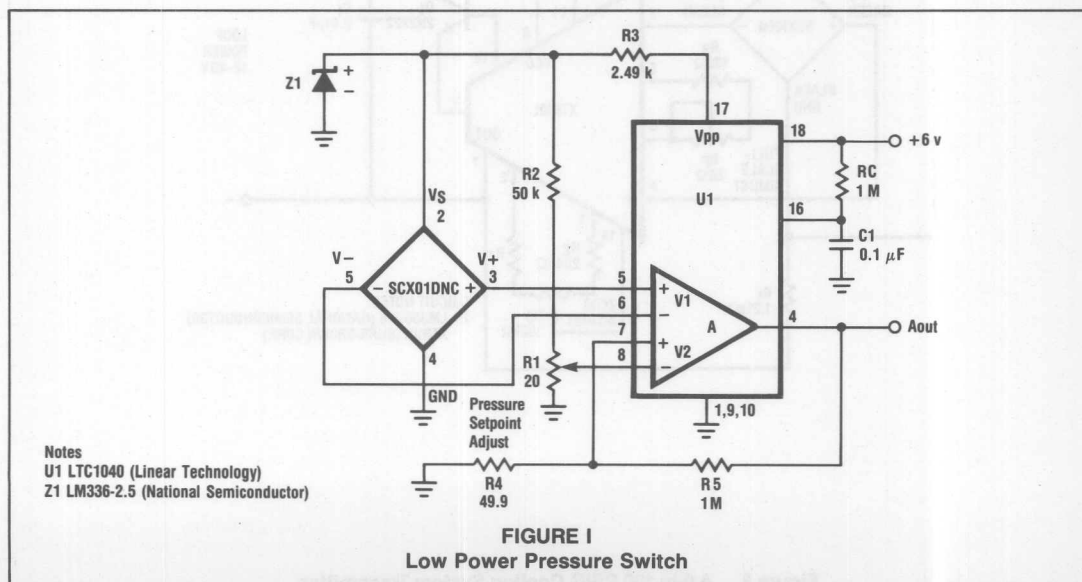
The basic low-power pressure switch consists of an SCX01DNC pressure sensor and an LTC1040 (Linear Technology) micropower comparator as shown in Figure 1.

Sensym

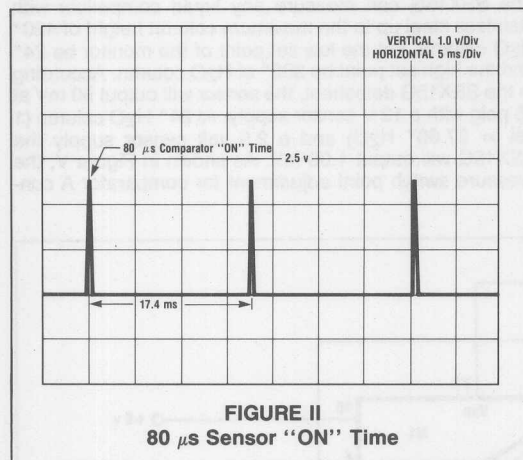
SSAN-31

To reduce power, the pressure sensor is powered by the pulsed power supply which is available on the LTC1040. The LTC1040 pulsed power output is configured such that with a 6v power supply the Vpp output will provide a 5.4 volt source when driving a 2.8 k Ω load. The Vpp output is unregulated, so the sensor and set point reference must either be ratiometric to the Vpp output voltage or referenced to a fast settling voltage reference (Z1) as shown in Figure 1. To minimize comparison errors, the voltage at the comparator inputs must be stable within 4 μ s of the start of the "ON" cycle. Although a variety of low-cost micropowered voltage references are available, many of these devices have response times as high as 100 μ s. Therefore, an LM336-2.5 (National Semiconductor) with a rise time of 2 μ s is used enabling the sensor outputs to settle within 3 μ s. This method of regulation allows consistent switching at the correct set points.

The SCX sensor typically has a 4 k Ω input impedance and it will therefore require 625 μ A of current at 2.5 volts. The LM336-2.5 requires 500 μ A to regulate properly, so together the sensor and the reference will need approximately 1.1 mA of current. By letting resistor R3 in Figure 1 be equal to 2.49 k Ω , the sensor and the reference will have 1.2 mA of current. The LTC1040's "ON" current is 1.2 mA, so the total current draw of the circuit is approximately 2.4 mA.

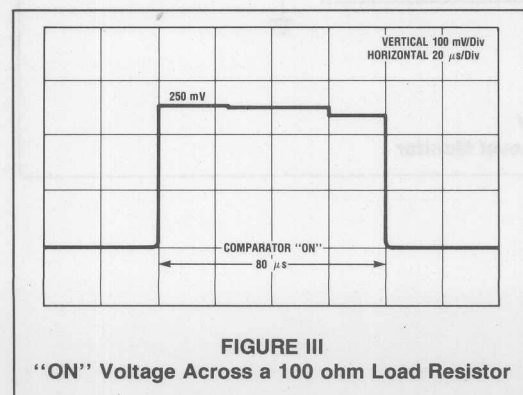


When the LTC1040 is in the "OFF" state, the comparator outputs will hold their logic levels, and the LTC1040 will require less than 30 μA of supply current. Therefore, this pressure switch is then able to consume very little power by powering the sensor for only 80 μs and shutting it off for the rest of the clock period as shown in Figure II. If the circuit in Figure I is set to a clock period of 17.4 ms, the average current draw is 41 μA or a 245 μW of power consumption. The current used during the comparator's 80 μs on time is verified as shown in Figure III where the supply current is calculated by measuring the voltage across a 100 Ω resistor.



Once power is supplied to the sensor, the comparator will sample the sensor output and the pressure set point. The comparator output is determined by the sum of the input voltages. In Figure I, if the sum of V_1 and V_2 are positive, A_{out} will be at a high logic level. If the sum is negative, A_{out} will be at a low logic level.

The circuit in Figure I shows a 6 volt power supply. If a different power supply is required, the pulsed power output, V_{pp} should be examined. The V_{pp} output is typically 0.8 to 1.0 volts below the power supply voltage for current loads of less than 3 mA. If a voltage supply of 3 volts is used, Z_1 needs to be changed to a 1.2 volt reference



(AD589, Analog Devices, Inc.), and R_3 is changed to a 750 Ω resistor. The resistors that set the switch point, R_1 and R_2 , do not need to be changed, because as V_E is increased or decreased, the sensor output, measured from V_1 and V_2 , is proportional to the same voltage reference. Therefore, once R_1 and R_2 are chosen, these resistor values will remain unchanged for different reference voltages. In Figure 1, only R_3 is changed to a 1.33 k Ω resistor in order to make the circuit compatible with a 5 volt power supply. Because the outputs of the comparator will swing to the power supply, when using a different power supply the comparator output must be compatible with the input range of the next device.

Hysteresis is added to the comparator to eliminate any jitter around the switching point. The amount of hysteresis added should be slightly larger than the maximum noise level of the comparator circuit. In Figure I, a 1 M Ω positive feedback resistor (R_5) with a 49.9 Ω resistor (R_4) to ground will provide 300 μV of hysteresis about the switching point. The amount of hysteresis is calculated by using the following equation.

$$V(\text{hyst.}) = \frac{R_4}{R_4 + R_5} A_{\text{out}}$$

Therefore, for this example,

$$V(\text{hyst.}) = \frac{49.9}{49.9 + 1 \text{ M}} 6 \text{ V}$$

$$V(\text{hyst.}) = 299 \mu\text{V}$$

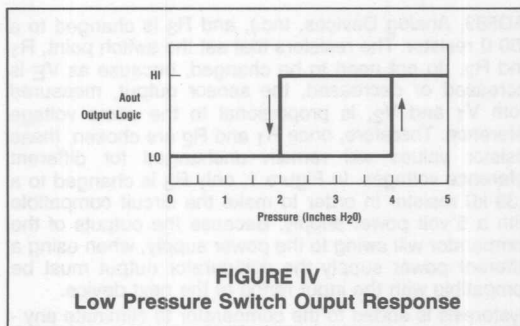
EXAMPLE 1—Air Filter Monitor

The differential pressure across an industrial filter is measured using an SCX01DNC in the basic switch configuration in Figure I. If we assume that a dirty filter is indicated by a 4" H_2O pressure drop across the filter, then let the output of the switch make a low-to-high logic transition at this pressure and trigger an alarm to the operator. According to the SCX01DNC data sheet, the sensor will output 18 mV at 1 psi with a 12 V power supply. With a 2.5 V excitation voltage and 4" H_2O column of pressure, the SCX01DNC will output 542 μV . A 20 Ω pot (R_1) and a 50 k Ω resistor (R_2) will allow V_2 to be adjusted between 0-to-1 mV in order to set the pressure switch point.

Notice that V_2 will be a negative voltage in respect to V_1 when the pressure differential is less than 4" H_2O column. The sum of V_1 and V_2 is negative, and the comparator output is at a logic low. When the pressure is greater than 4" H_2O column the sum of V_1 and V_2 is greater than zero, and the comparator output will be at a logic high.

A 1 M Ω resistor with a 49.9 Ω resistor provides 2" H_2O column of hysteresis as shown in Figure IV. When the logic output is high, the feedback from the 1 M Ω resistor will reduce the magnitude of V_2 thereby causing the comparator to switch from high to low logic level at a pressure 2" H_2O column lower than the pressure set point.

The circuit as shown is self clocking at 5 Hz with RC equal to 1 M Ω and C_1 equal to 0.1 μF . At this frequency, the average power consumption is 31 μW . If a small battery of 6 V and capacity of 250 mA $\cdot$ H was used to power this circuit, the circuit has a potential of lasting over five years.



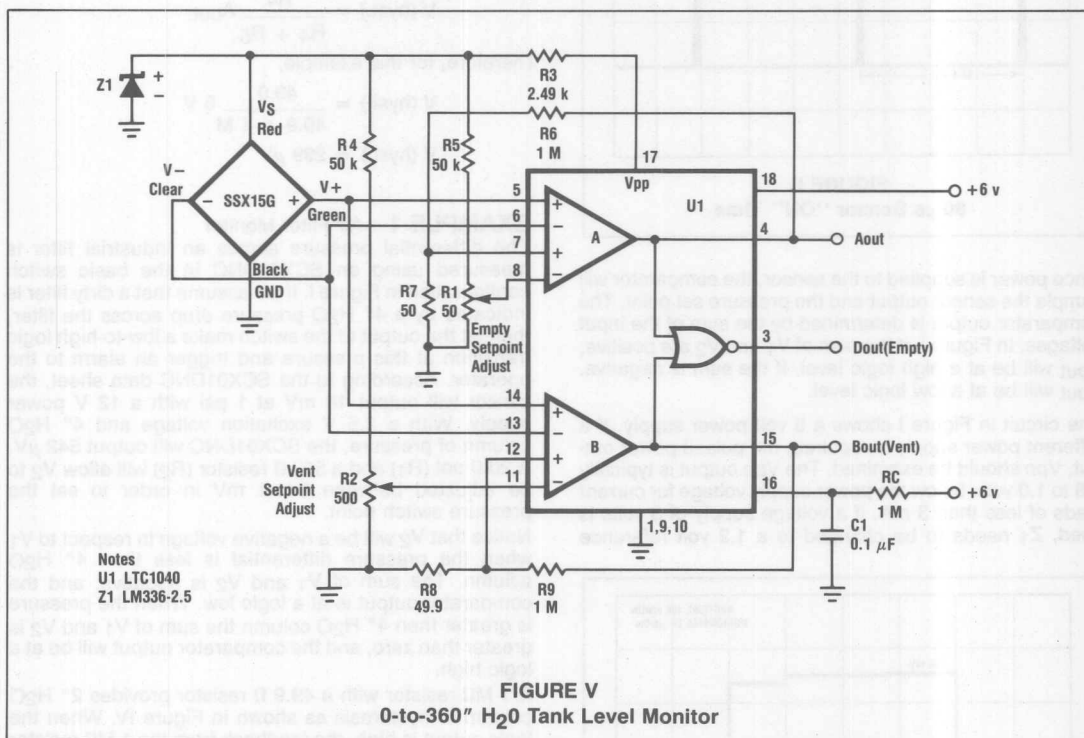
Adjustment Procedure

- Apply 4" H₂O column to the sensor and adjust R1 until the comparator output makes a low-to-high logic transition.
- Repeat the procedure as necessary.

Example 2—Tank Level Monitor

A 35 foot high storage tank is remotely located, and periodically the main circuit of the controller is powered up to take a reading of the liquid level. During the "OFF" state, a tank level monitoring circuit senses the liquid level of a storage tank and warns of any leaks or any dangerous build up of pressure. This monitoring must consume very little power, because all the circuitry is battery powered.

By using the built-in features of the SSX15G and the LCT1040 a simple micropower window comparator can be constructed for this application as shown in Figure V. The SSX15G can measure any liquid compatible with stainless steel up to the maximum column height of 420" H₂O column. Let the low set point of the monitor be 24" and the high set point be 360" of H₂O column. According to the SSX15G datasheet, the sensor will output 90 mV at 15 psig with a 12 V sensor supply. At 24" H₂O column (1 psi = 2.768" H₂O) and a 2.5 volt sensor supply the SSX15G will output 1.08 mV. As shown in Figure V, the pressure switch point adjustment for comparator A con-



sists of a 50 Ω pot and a 50 k Ω resistor to allow a 0-to-2.5 mV adjustment. For the higher switch point, the SSX15G will output 16.3 mV at 360" H₂O. A 500 Ω pot and a 50 k Ω resistor will provide a 0-to-25 mV adjustment.

By using the logic gates on the LTC1040, the monitor will signal the microprocessor with a logic high signal when the tank has less than 24" of liquid left, or when over 360"

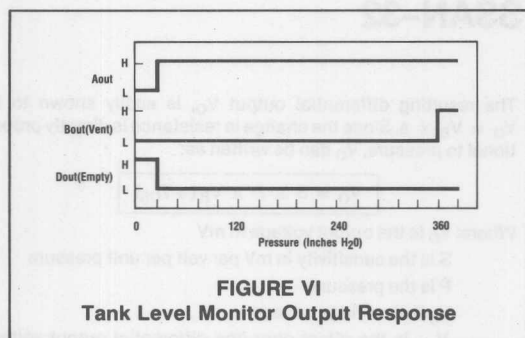


FIGURE VI
Tank Level Monitor Output Response

H₂O pressure is building in the tank, and needs to be vented. Figure VI shows the output response of the "vent" and "empty" signals as a function of pressure.

Adjustment Procedure

- Apply 24" H₂O of pressure to the sensor, and adjust R₁ until the A_{out} signal line changes from a low-to-high logic transition.
- Apply 360" H₂O of pressure to the sensor, and adjust R₂ until the B_{out} (Vent) signal changes from a low-to-high logic transition.
- Repeat procedure as necessary.

Conclusion

By using Sensym's SCX or SSX series of pressure sensors with an LTC1040, an accurate micropower pressure switch can be achieved. These electronic pressure switches can be especially useful in low-power or battery operated circuits.

Understanding Constant Voltage and Constant Current Excitation for Pressure Sensors

By Scott Weatherwax

INTRODUCTION

Low cost solid state pressure sensor elements have attracted a great deal of attention lately. Although for the bulk of applications it is more economical to use a device which is calibrated by the sensor manufacture, for some very high volume OEM applications a basic sensor element can be used. It is when using these uncompensated elements that one needs to be able to understand the various methods for span temperature compensation.

A misconception existing today among many engineers is that the basic piezoresistive pressure sensor elements come in two types—constant voltage and constant current. Although the basic sensor elements are often referred to as either constant current or constant voltage driven sensors, what is really being referred to is the method of span temperature compensation utilized. The two basic methods of compensation for the sensors inherent decrease in sensitivity over temperature are: (1) Using the internal characteristics of the die in conjunction with a constant current source, or (2) Using thermistors or other similar devices in conjunction with a constant voltage source. This article will explain the difference between the two types of compensation, clarify what is meant by the terms constant voltage and constant current as it applies to piezoresistive pressure sensors, and provide guidelines for which type of die is best for a given application.

GENERAL INFORMATION

Many different types of piezoresistive pressure sensors are available. They cover pressure ranges from below 1 psi to pressures well above 10,000 psi and are available in a variety of package styles and voltage outputs. However, for all integrated solid state piezoresistive sensors the basic operating principle of the sensor element remains unchanged. Figure 1 shows the schematic diagram of a typical solid state pressure sensing element. These devices use diffused or ion implanted resistors in an integral silicon diaphragm to transform the related stress, due to pressure, into an electrical output. The solid state pressure die functions as a wheatstone bridge. As pressure is applied the resistors in the arms of the bridge change by some amount Δ .

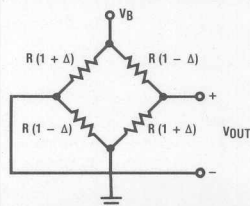


FIGURE 1
Schematic Diagram of Piezoresistive Pressure Sensor

SenSym

SSAN-32

The resulting differential output V_O , is easily shown to be $V_O = V_B \times \Delta$. Since the change in resistance is directly proportional to pressure, V_O can be written as:

$$V_O = S \times P \times V_B (+V_{OS}) \quad (1)$$

Where: V_O is the output voltage in mV

S is the sensitivity in mV per volt per unit pressure

P is the pressure

V_B is the bridge voltage

V_{OS} is the offset error (the differential output voltage when no pressure is applied).

The offset voltage and the related offset temperature errors can be critical error parameters for some applications. However since the method of excitation, constant current or constant voltage, will not significantly impact these parameters, they will not be covered in this discussion.

Equation (1) is simple and no additional circuitry would be needed for temperature compensation if not for the fact that the sensitivity, S , changes quite dramatically with temperature. In fact, all piezoresistive die have two inherent characteristics: (1) A decrease in sensitivity with increasing temperature, which is referred to as the temperature coefficient of span (TCS). (2) An increase in the bridge resistance with temperature, known as the temperature coefficient of resistance (TCR).

One can better understand how to compensate for this change in sensitivity by looking at the derivative of equation (1) with respect to temperature. Ignoring the V_{OS} term gives:

$$\dot{V}_O = P(\dot{S} V_B + S \dot{V}_B) \quad \text{Note 1}$$

When a sensor is properly compensated the output voltage does not change with temperature. Hence, $\dot{V}_O = 0$ and:

$$S \dot{V}_B = -\dot{S} V_B \quad \text{or,}$$

$$\frac{\dot{V}_B}{V_B} = -\frac{\dot{S}}{S} \quad (2)$$

This equation tells us that in order to compensate for the change in sensitivity with temperature, the bridge voltage must change in equal magnitude in the opposite direction. Therefore, the goal of any/all compensation schemes shown in this article is to change the bridge voltage with temperature such that the

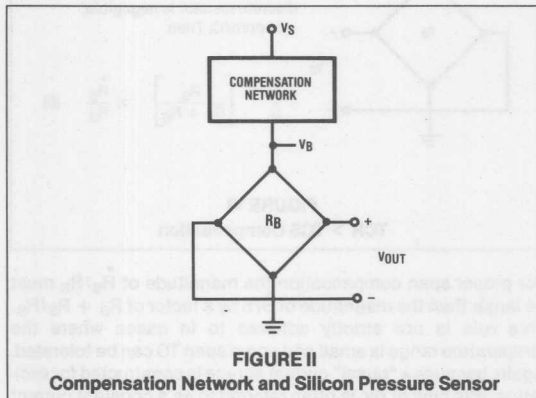
Note 1: In this discussion, for simplicity of notation, the change of a variable with temperature will be designated with a dot (.) over the variable. For example,

$$\frac{\Delta S}{\Delta T} = \frac{\text{change in sensitivity}}{\text{change in temperature}} = \frac{ds}{dT} = \dot{S}$$

sensitivity will not vary with temperature. This is true regardless of the compensation method used. Some examples of the different compensation techniques are now given.

COMPENSATION TECHNIQUES

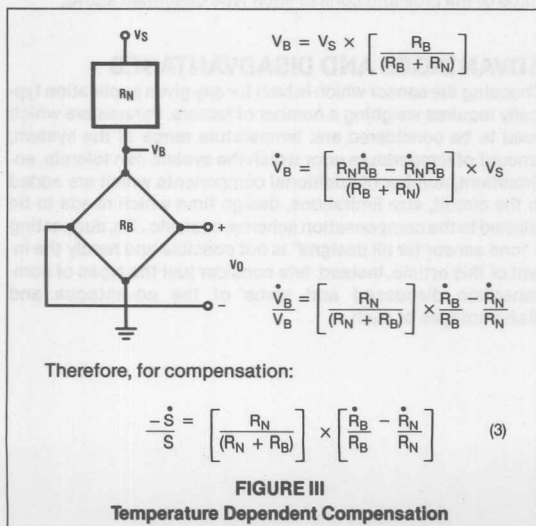
As noted previously, due to the effects of TCS, all piezoresistive pressure sensor die will exhibit a decrease in sensitivity with temperature so they will not be properly compensated if a fixed voltage source is placed directly across the bridge. In order to stop, or at least limit, the change in sensitivity with temperature, a compensation network must be utilized.



Typically, the compensation network will take on one of the following forms.

(1) Temperature Dependent Resistive Components

In this method, an additional circuit consisting of resistors and thermistors, or similar components, are most often added by the manufacturer to the pressure sensing die for span compensation. Remembering that the goal of this compensation method is to change the bridge voltage with temperature a simple compensation network can be modeled as follows:

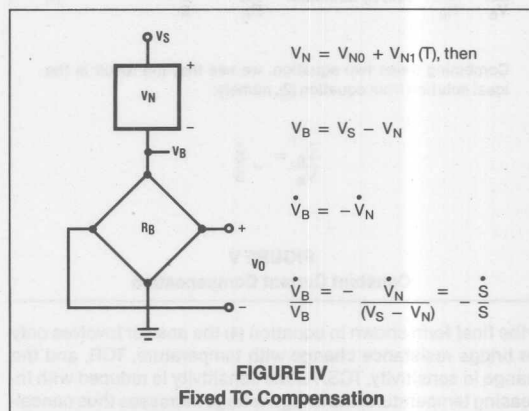


Note, that the correct compensation scheme for equation (3) does not involve the power supply voltage. In fact, the output is ratiometric to the supply voltage and devices utilizing this method of compensation can operate over a large input voltage range. Because the device is operated by a voltage source, when this method of compensation is used with a sensor, the end product is often referred to as a constant voltage sensor.

The main problem associated with this scheme for low to medium volume applications is that thermistors and resistors, for optimum results, must be individually matched to the sensors. Because low cost, off-the-shelf thermistors are not well controlled, this method really only make sense for very high volume manufacturing where thick film networks with laser trimmed circuits can be utilized.

(2) Fixed TC Compensation

This compensation technique consists of using diodes or other active components which have a fixed voltage change with temperature. The mathematical model is similar to the model shown in method (1). Assuming that the voltage across the compensation network, V_N , is equal to:



However, one major difference does exist between this method and the previous method. Since V_N and V_N are fixed properties of the diode (or other active device used) and these are not ratiometric to the supply voltage, V_S , this compensation method performs well at only one particular value of the supply voltage. Any variation in supply voltage will cause an error in the span TC compensation. Again, because a voltage source is used, this method also yields what is typically referred to as a constant voltage sensor.

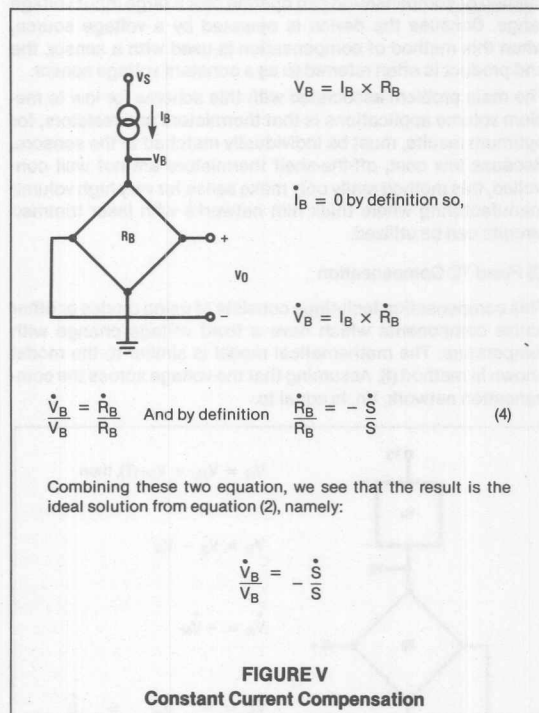
The one advantage of this simple scheme is that low cost, off-the-shelf diodes and transistors are readily available with fairly well known temperature characteristics so that this compensation method can easily be added by the end user.

(3) Current Source Compensation, $TCR = -TCS$

The exact value of the TCR and TCS in the die considered thus far have not been of particular concern because the components that were added, compensated the sensor for any reasonable value of TCR and TCS found in piezoresistive sensors.

However, the pure current source compensation scheme has a specific requirement: The TCR must be equal in absolute magnitude and opposite in sign with the TCS ($TCR = -TCS$). Given

this characteristic, the die will obtain optimum performance over temperature when operated from a constant current source. The model is shown below:

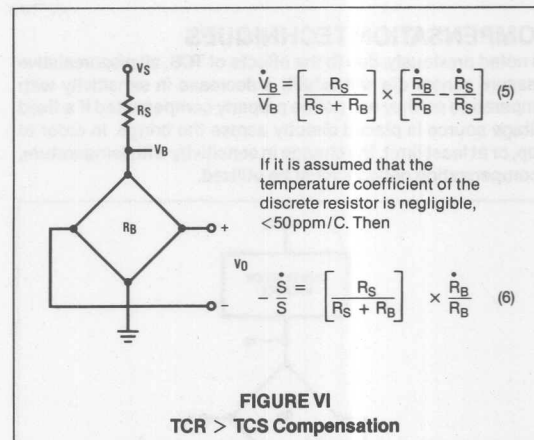


In the final form shown in equation (4) the answer involves only the bridge resistance change with temperature, TCR, and the change in sensitivity, TCS. As the sensitivity is reduced with increasing temperature, the bridge voltage increases thus canceling any change in sensitivity. Such a system is often referred to as self-compensating, and because the die is operated from a constant current source the die is often referred to as constant current sensor.

(4) TCS Smaller Than TCR Compensation

This is one of the more common types of solid state sensor die available today. In this product, the TCR is slightly larger than the TCS in absolute magnitude, and span temperature compensation can be adjusted by adding a single resistor in series with the sensing element if voltage excitation is used. This device can also be used with a true constant current source and span TC can be adjusted by adding a single resistor in parallel with the bridge to effectively reduce the TCR of the device. When using this device with a constant voltage source, a large resistor

must be added to the network so a "quasi" constant current source provides power to the sensor. The mathematical model is shown below:



For proper span compensation the magnitude of $\dot{R}_B/R_B$ must be larger than the magnitude of $\dot{S}/S$ by a factor of $R_B + R_S/R_S$. This rule is not strictly adhered to in cases where the temperature range is small and some span TC can be tolerated. Again, because a "quasi" current source is constructed for excitation, this type of die is often referred to as a constant current sensor.

Other types of span temperature compensation do of course, exist but the four examples shown here are the most common. It should also be noted that no matter which type of excitation is used, constant voltage or constant current, what is really being referred to with the terms constant current and constant voltage sensors is the type of span compensation that the particular die best utilizes. The next section may offer some guidance in choosing which type of span compensation, and hence which type of sensor, is best for a particular application by listing some of the pros and cons of each type described above.

ADVANTAGES AND DISADVANTAGES

Choosing the sensor which is best for any given application typically requires weighing a number of factors. Parameters which need to be considered are: temperature range of the system, amount of temperature error which the system can tolerate, environment, number of additional components which are added to the circuit, size limitations, design time which needs to be allotted to the compensation scheme, cost, etc.. So, suggesting a "one sensor for all designs" is not possible and hardly the intent of this article. Instead, let's consider just the types of compensation discussed and some of the advantages and disadvantages of each.

(1) TCR > TCS Compensation

As mentioned before this is probably the most common type of pressure sensor die sold. At first glance, this appears to be the perfect solution, simply by adding an addition resistor the span temperature compensation can be accomplished. However, drawbacks do exist when using this type of die over wide temperature ranges or in high accuracy applications. If equation (6) is solved for R_S , we can see some of the shortcomings.

$$R_S = R_B \frac{(-TCS)}{TCR + TCS} \quad \text{Where } TCS = \frac{\dot{S}}{S}$$

$$\text{and } TCR = \frac{\dot{R}_B}{R_B}$$

In order to select the proper value of series resistor, R_S , the bridge resistance, R_B , as well as the TCR and the TCS must be known. And unless each die is characterized, the typical values must be used. Using the typical values could result in span temperature errors of a few of hundred ppm/°C. Also, because the TCR usually exceeds the /TCS/ by less than 50%, the resistance of the series resistor, R_S , is larger than the bridge resistance, R_B , resulting in a lower voltage across the bridge and hence a lower overall sensitivity. Less obvious with a TCR > TCS type of die are the second order effects inherent in the die itself. These second order effects can potentially limit the useful temperature range to 25°C ± 15°C.

Also, it should be noted that V_{OS} and $\dot{V}_{OS}$, while not the topic of this discussion, must also be compensated for accuracy over a wider temperature range. Therefore, additional components will be necessary, along with extensive testing by the end user of a TCR > TCS die if high accuracy is required.

(2) TCR = -TCS Compensation

Unfortunately, this method of compensation has many of the same drawbacks as the single resistor method shown above. The overall sensitivity of the device can be reduced due to the voltage drop across the current source. Although there are fewer variables effecting the TCS, second order effects again limit the compensated temperature range of this device, to typically 25°C ± 25°C for reasonable accuracies. And, again V_{OS} and $\dot{V}_{OS}$ are not compensated in this method. This method is best where one does not want to individually characterize the sensor devices and accuracies of 1% to 2% over 50°C are acceptable.

(3) Fixed TC Compensation

This method of compensation has been used as an integrated solution in the past, but is seldom used today because it has the same disadvantages of the above compensation schemes and in addition must be operated from a specific voltage. However, this method does allow the user to use a die with less specific TCR and TCS characteristics. But some forethought is required. Because the power supply is a fixed voltage, characterization over temperature of both the die and the fixed TC device used is strongly recommended to assure that the compensation

method will meet the users demands. Variations in the exact TC values of the die and the fixed TC device used may cause some TC error. The overall temperature range of this type of die is again usually limited to 25°C ± 25°C.

Also, because the die and the compensation circuit are not located in the same physical place, this type of design has the added disadvantage in that the die and the compensation network might be at different temperature. However, few systems experience a drastic change in temperature in a short period of time, so the difference in temperature between the die and the compensation circuit are usually small.

(4) Temperature Dependent Resistive Components

By using this type of compensation scheme the sensor can be operated over a large input voltage range, while the output voltage remains ratiometric to this supply voltage. This type of span TC compensation is the optimum solution if the user is running very high volumes and can individually test and laser trim each device to exact tolerances. In addition then, one can adjust the sensitivity to a very narrow range as well as compensate for V_{OS} and $\dot{V}_{OS}$. This method with individual trimming also allows the designer to compensate for second order effects of the die, thus yielding a wider temperature range, -20°C to 70°C. (With somewhat reduced performance the temperature range is -40°C to 100°C.)

The trade-off for this improved performance is the cost and an over-all increase in the package size of the sensor, since the compensated sensor contains not only the die, but also a thick film compensation circuit. Again, because the die and the compensation network are not located in the same physical location, the die and the compensation network may be at different temperatures, causing some of the problems described in (3) above. However, for the user who cannot individually test and laser trim, this option is probably the least attractive where discrete components must be used.

CONCLUSION

Piezoresistive pressure sensors are often referred to as either constant current or a constant voltage sensors. However, what is really being referred to is the type of span temperature compensation that the die is utilizing.

Although other factors need to be considered, two of the main considerations when choosing to use a low cost basic pressure sensor element are: The operating temperature range of the system and accuracy required. Once these considerations have been established, the actual choice of sensors will be simplified. There is no "cure all" sensor die however, and all die must be compensated for temperature effects. And, although span temperature compensation was the primary variable of concern in this note, for any application where high accuracy over temperature is required, offset shifts with temperature also must be accounted for.

Of course, for all applications except very high volume ones, a sensor which is compensated by the manufacturer is generally the most cost effective solution. A variety of these products are available including those which add span and offset compensation calibration networks and even full amplification to the basic sensor die.

Mounting and Pressure Connection Options Using the Basic Sensor Package

By Duane Tandeske

INTRODUCTION

The basic sensor package (sometime referred to as the button package) is a small plastic and aluminum (0.5 inch diameter, by 0.2 inch thick) pressure sensor package. All basic sensor elements are available in the basic sensor package. The basic sensor package is the first stage in the assembly process which allows pressure to be applied to the sensor, these sensors are the lowest cost tested sensor available from SenSym. The basic sensor package has no pressure ports or mounting holes, pressure is applied to the sensor through 0.040 in. holes located in the top and bottom aluminum surfaces of the package. This application note will discuss the mounting and pressure connection options when using a sensor in the basic sensor package.

PHYSICAL DIMENSIONS

The basic package has three parts, a Ultem (nylon), transfer molded, body with electrical lead frame, a aluminum bottom cover (0.050 thick), and a aluminum top cover (0.020) thick. The two aluminum covers are heat staked into the Nylon housing which increases the dimensions of the nylon body. For this reason it is not recommended to use the nylon body as a sealing surface. Figure I shows the physical dimensions of the basic sensor package and shows the recommended sealing surfaces.

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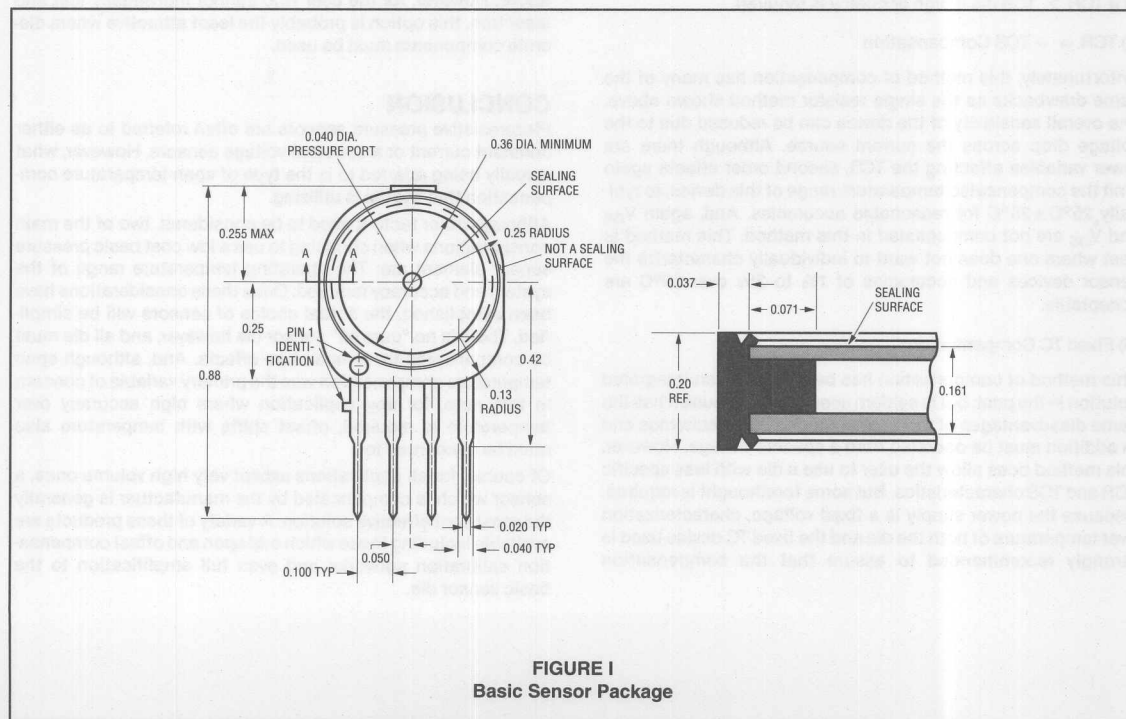
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PACKAGE MATERIALS

1. Plastic body - Ultem 1000
2. Sealing surfaces Aluminium
3. Die attach RTV G.E. 128
4. Protective coating Dow 527 Sil. Gel.

MOUNTING OPTIONS

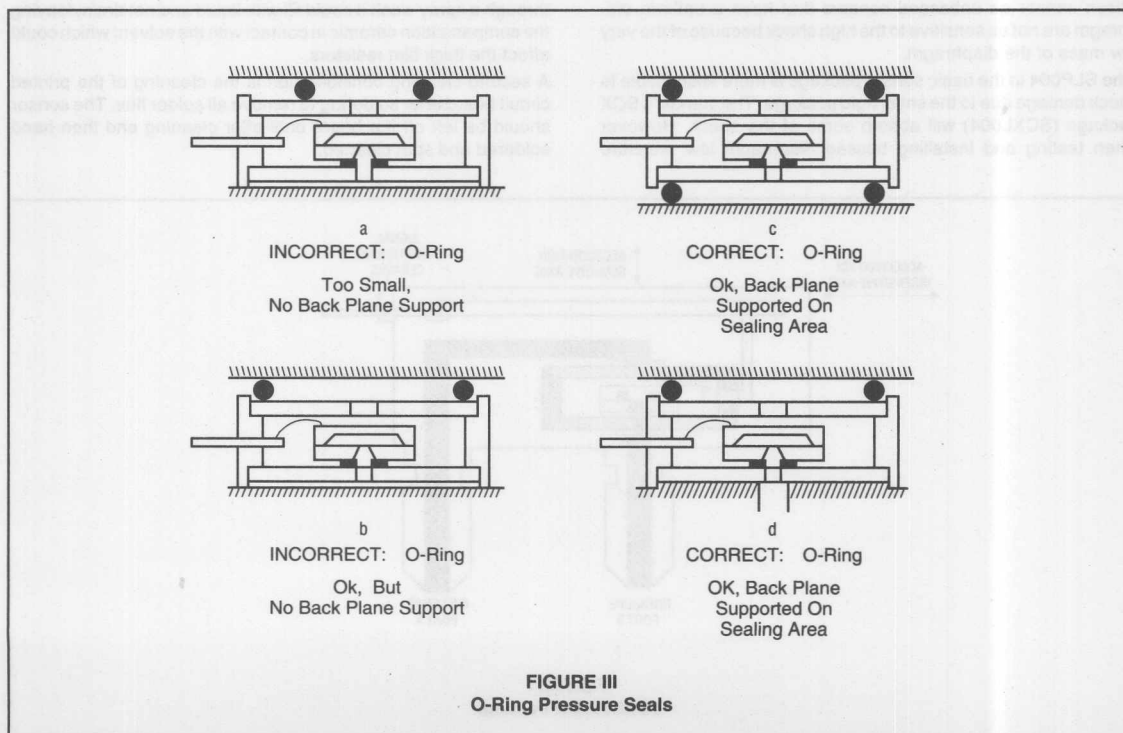
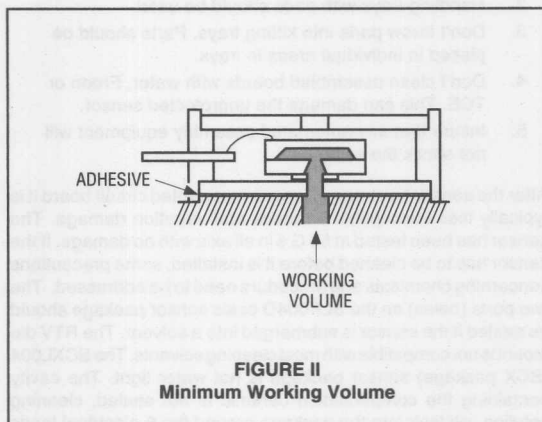
The two most popular mounting techniques are to mount the sensor by means of an adhesive seal to a mating surface or to use O-ring face seals to the aluminium sealing surfaces. The O-ring face seal would be used for testing purposes and in applications that require the sensor to be removable.



PRESSURE CONNECTIONS

Adhesive Seal (no tubing) — To achieve a minimum working volume the pressure sensor can be mounted directly to the pressure vessel. The internal volume of the sensor is 1 cubic millimeter at the p2 port and 35 cubic millimeter at the p1 port. A minimum working volume can be achieved by sealing p2 to the pressure source as shown in Figure II. The seal should be made to the aluminium surface not the nylon body.

O-Ring seal — An O-ring seal (face seal) can be used on either sealing surface to do a functional pressure test or to incorporate the pressure sensor into a system. Figure III shows both correct and incorrect O-ring seals:



CONCLUSION

The basic sensor package is a small, light weight pressure sensor that can be incorporated into larger pressure based systems or used as a stand alone pressure monitor or indicator. The basic sensor package should be used when size, weight, or minimum working volume is needed.

SCXL004DN and SLP004D Handling and Installation Techniques

By Duane Tandeske

INTRODUCTION

The SCXL004DN and SLP004D are very low pressure sensors which have been designed to maximize sensitivity at very low pressure levels. A thin diaphragm in the silicon sensor ship has been designed to concentrate the strain at the piezoresistive bridge resistor locations. The center of the diaphragm has not been etched leaving a pyramid shaped structure which stiffens the diaphragm and localizes the strains at the outer edges where the sensing resistors are located. This diaphragm design is referred to as a "bossed diaphragm". A bossed diaphragm increases the sensitivity to pressure by a factor of ten but having a large mass in the center of the diaphragm makes the sensor more susceptible to shock and vibration. This application note will discuss mounting considerations and unique problems associated with handling and installing these low pressure bossed diaphragm sensors.

HANDLING CONSIDERATIONS

If the sensor is dropped three feet onto a hard surface such as a table top or tile floor and lands so that the force is in the sensitive axis (See Figure 1) then the large mass in the center of the diaphragm will generate enough force to break the diaphragm. (As a note a drop of three feet onto a hard surface will generate thousands of G's). This has not typically been of concern for other silicon sensor as unbossed sensors that have a uniform diaphragm are not as sensitive to the high shock because of the very low mass of the diaphragm.

The SLP004 in the basic sensor package is more susceptible to shock damage due to the small rigid package. The standard SCX package (SCXL004) will absorb some of the shock. However when testing and installing bossed diaphragm low pressure

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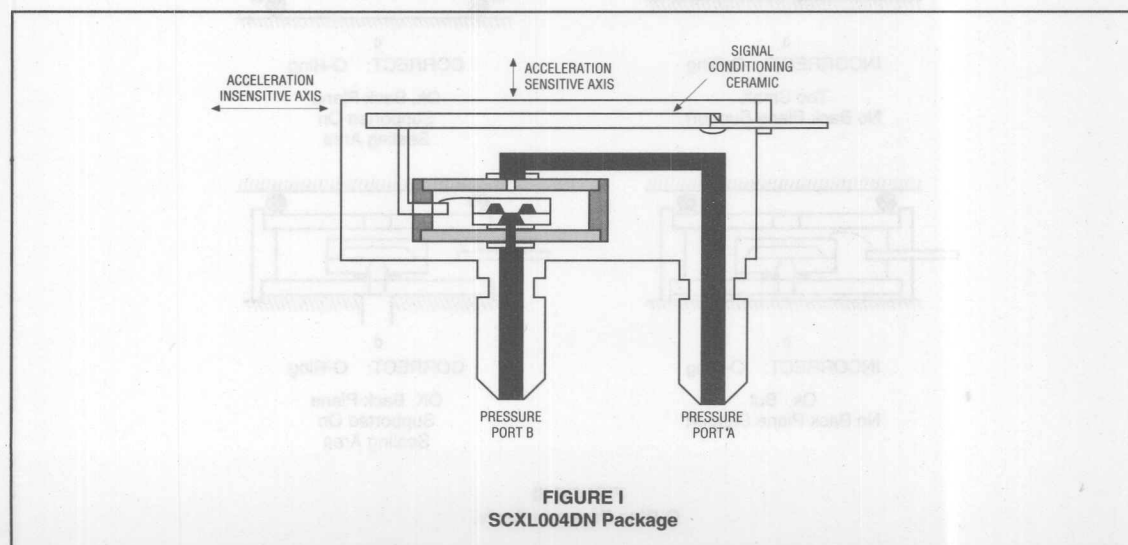
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sensors the following assembly Precautions will help minimize any handling and assembly related problems:

1. Use a rubber matted work area.
2. Handling trays with pads should be used.
3. Don't throw parts into kitting trays. Parts should be placed in individual areas in trays.
4. Don't clean assembled boards with water, Freon or TCE. This can damage the unprotected sensor.
5. Insure that any automated assembly equipment will not shock the sensor.

After the sensor has been mounted on a printed circuit board it is typically less susceptible to shock and vibration damage. The sensor has been tested at 50 G's in all axis with no damage. If the sensor has to be cleaned before it is installed, some precautions concerning chemicals and procedure need to be addressed. The two ports (holes) on the SLP004D basic sensor package should be sealed if the sensor is submerged into a solvent. The RTV die mount is not compatible with most cleaning solvents. The SCXL004 (SCX package) sensor package is not water tight. The cavity containing the compensation ceramic is not sealed, cleaning solution will leak into the package around the 6 electrical leads and the edges of the package. If the package is submerged or run through a spray wash it could fill with liquid and not drain, leaving the compensation ceramic in contact with the solvent which could effect the thick film resistors.

A second cleaning consideration is the cleaning of the printed circuit board after soldering to remove all solder flux. The sensor should be left off the board until after cleaning and then hand soldered and spot cleaned.



OVERPRESSURE

Exceeding the overpressure specification is another consideration when installing the sensor. If a very compliant tubing is used (such as silicon tubing) a large pressure can be generated when the tube is installed. If the tube is squeezed closed a half inch from the end and pushed over the sensor pressure port a pressure of 15 psi or more can be generated. If 14.7 psi is trapped in the end of the tube (one atmosphere) and the internal volume is reduced by 50% the resulting pressure is 29.4 psia or + 14.7 psig. To insure that a high pressure is not generated, the tube should be supported by placing a small piece of rigid tubing over the silicon tubing to ensure that it is not pinched closed during installation. See Figure II. If possible the system should be vented to atmosphere at the time the sensor is installed.

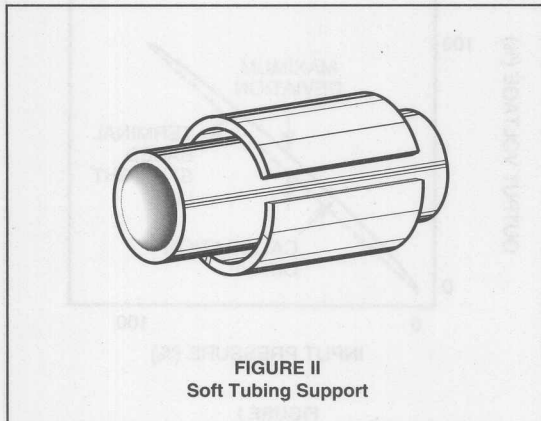


FIGURE II
Soft Tubing Support

MOUNTING CONSIDERATIONS

Mounting SCX series sensors on printed circuit boards is discussed in application note SSAN-25 (Installation Techniques for the SCX Series Sensors). Since the SCXL004DN is packaged in the standard SCX package we recommend using the same mounting techniques. The right angle socket and Christmas tree clips will minimize shifts in the offset voltage due to package sensitivity.

The mass in the center of the diaphragm makes the sensor position sensitive, if the offset is adjusted with the sensor positioned as shown in figure 1 (+ 1 G) and then rotated 90 degrees the offset will change 0.025 in. H₂O (0.25mv.). The sensor should be calibrated in the position it will be used.

A bossed pressure sensor is a low sensitivity accelerometer. If the sensor is vibrated in the plane in which the diaphragm deflects, the output will change at a rate of 0.25 mv./G. To minimize the acceleration effect the sensor should be mounted so that the acceleration is at a right angle to the sensitive plane. (See Figure I.)

Another consideration when mounting the sensor is reliability. As with any sensor the sensor should be mounted in the system so that anything that may condense in the pressure lines will flow away from the sensor. If the sensor is mounted at the lowest point in the system any liquid in the line will gravity flow into the sensor and be collected there. Mounting the sensor with the pressure ports positioned up or placing a trap in the line before the sensor will improve reliability.

The sensor is a silicon chip which uses pure aluminium electrical contact pads. Applying a liquid to the top of the sensor that oxidizes aluminium will result in an open contact (The A Port on the SCXL004). The B port can be used to measure liquids that are compatible with the package materials.

CONCLUSION

The SCXL004 and SLP004 pressure sensors have been designed to measure very low pressures by using a bossed diaphragm. This diaphragm design increases the sensitivity of the sensor but it also makes the sensor more susceptible to shock and vibration. However, by following some simple assembly precautions, these sensors can be used to reliably and accurately measure very small pressures.

Linearity Error As a Function of Working Pressure

By Duane Tandeske

SenSym

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INTRODUCTION

In the process of selecting a pressure sensor one of the first considerations is accuracy. Static accuracy is typically defined as the combined effects of linearity, hysteresis, and repeatability errors and is expressed as % of full scale. Single crystal silicon pressure sensors have no moving parts and as a result the mechanical hysteresis is virtually nonexistent. This leaves linearity and repeatability as the two major accuracy errors. Repeatability is a constant (independent of the pressure range) while the amount of linearity error (percent of working pressure) will vary proportionally to working pressure. This application note will discuss the changes in linearity error when a piezoresistive pressure sensor is operated at pressures above and below the operating pressure range given on the data sheet.

DEFINITION OF LINEARITY

Linearity is defined as the closeness which a sensor output calibration curve approximates a ideal straight line. The maximum error is expressed as a percent of full scale. ISA standard ISA-S37.3 (Specification and tests for strain gage pressure transducers) lists 5 types of linearity error: namely, end point, independent (best straight line), least squares, terminal, and theoretical slope. This application note will limit the discussion to independent and end point linearity.

End point linearity — fixes both ends of the sensor calibration curve, 0 psi = 0 volts, and x psi = x volts. The maximum nonlinearity is at 50% pressure.

Independent linearity — positions the calibration curve on the calculated straight line with maximum deviation on both sides of the calculated straight line.

Independent linearity will result in a number approximately half the end point number. If a data sheet does not specify a test procedure independent is assumed.

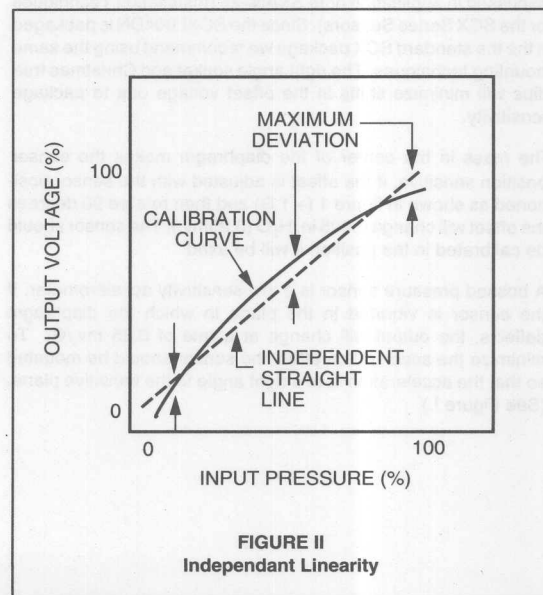
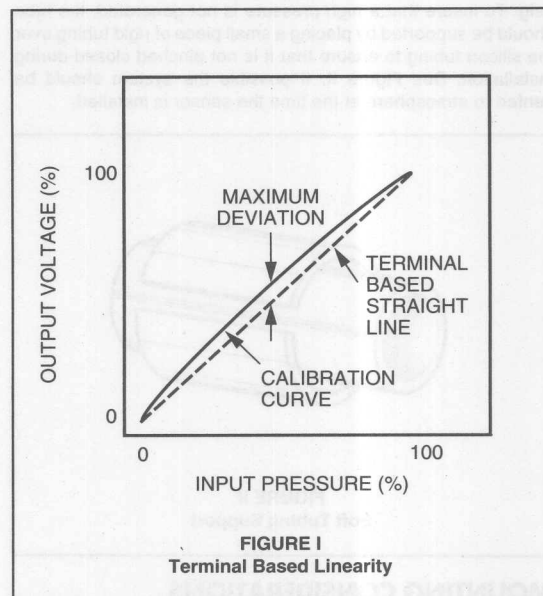
HOW TO MEASURE LINEARITY ERRORS

Linearity errors are calculated by applying 0 psi, ½ working pressure, and full working pressure to the sensor and recording the output voltage at each pressure. End point linearity is calculated:

$$Lin = \left(\frac{P_3 - P_1}{2} + P_1 \right) - P_2$$

Where P_1 = 0 pressure
 P_2 = ½ working pressure
 P_3 = full working pressure

The linearity error in volts is then compared to the full scale output in volts to get percent error. The independent error is ½ the calculated end point error. Figures I and II show typical terminal based and independent linearity curves.



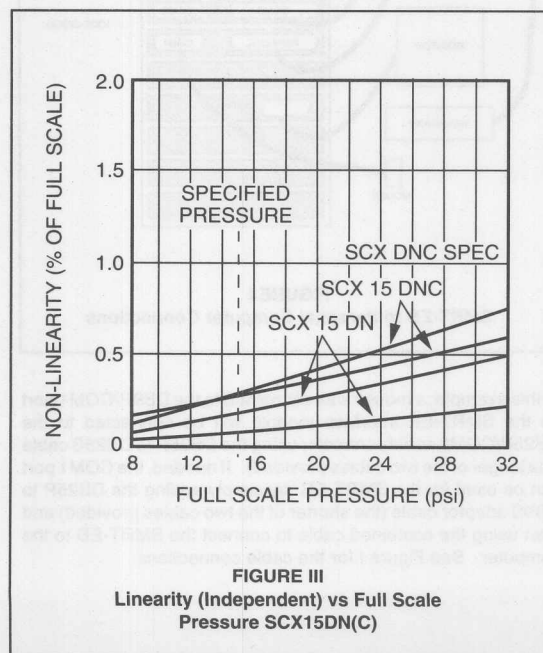
LINEARITY AS A FUNCTION OF WORKING PRESSURE

Linearity error is dependent on the applied pressure, the maximum error is at 50% of the maximum pressure. If the system is calibrated at 0% and 100% pressures the linearity error is 0 at 0% and increases to a maximum at 50% pressure, above the 50% pressure the error decreases and is 0 at 100% pressure. The number specified on the sensor data sheet is the maximum allowed error at 50% of the operating pressure range. Specific reference testing conditions are given for each sensor. The reference conditions allow the user to test the device under the same conditions as the manufacturer. For use outside the rated or specified pressure range, one can use a rough guide line as follows:

1. The percent of full scale nonlinearity varies proportional to working pressure.
 - a. A 15 psi sensor will have approximately half the percent of full scale nonlinearity at 7.5 psi as at 15 psi.
 - b. A 15 psi sensor will have approximately twice the percent of full scale nonlinearity at 30 psi as at 15 psi.

Note that these are rough guidelines only and the factory should be consulted for specific details on a given product. Also the maximum overpressure should be taken into consideration when over pressuring a pressure sensor (a 15 psi sensor is rated at 30 psi maximum).

As an example Figure III shows the nonlinearity of four SCX15 DN(C) sensors as a function of operating pressure. It should be noted that the graph represents nonlinearity (percent of full scale) from 8 to 30 psi and that the percent of maximum working pressure error increases as a function of working pressure.



SMRT TRANSDUCERS

SenSym has introduced a new series of digitally compensated pressure transducers that virtually eliminates the conventional linearity error. The SMRT series measures each sensor over pressure and temperature and stores the data in the internal microprocessor. As each pressure measurement is made the microprocessor measures the output of the pressure sensor and a internal temperature sensor, the microprocessor then looks up the corrected pressure reading from memory. The compensated output signal has been temperature compensated and linearized by the microprocessor.

CONCLUSION

The shape of the sensor calibration curve does not change but operating on different areas of the curve results in a proportional linearity error. The linearity error of sensors operated at pressures below the specified operating pressure will be less than sensors operated at or above the specified pressure. In some applications where temperature error and resolution are of prime importance a sensor can be operated above the specified operating pressure range. For example 1 psi and 5 psi are standard pressure ranges, to measure 2.5 psi should a 1 psi or 5 psi sensor be used? If offset TC and sensitivity are more important than linearity a 1 psi sensor should be used. However if minimizing linearity error is the prime consideration a 5 psi sensor would be used instead. Linearity errors can always be reduced by using a higher rated, less sensitive device but one must always look at the overall system needs.

High Accuracy Computer Controlled Barometer

By Dale Dauenhauer

INTRODUCTION

Many computer controlled applications require a barometric pressure reading. System requirements often dictate higher accuracy outputs and a digital output signal format which typical analog pressure sensors can not provide. To accommodate such applications, SenSym has developed a highly accurate digital output sensor the SMRTBAR01 pressure sensor and a printed circuit board RS-232 interface module the SMRT-EB. The SMRTBAR01 is temperature compensated from -20°C to 85°C to an overall accuracy of 0.5% FSO maximum, has a pressure range of 20.0 In. Hg to 32.0 In. Hg and has typical static accuracies (combined linearity, hysteresis and repeatability) of $\pm 0.04\%$ or (± 0.013 In. Hg). These tight specifications make the SMRTBAR01 ideally suited for high accuracy barometric applications.

The SMRT-EB is an assembled printed circuit board containing all the necessary hardware to operate the SMRTBAR01 through a computer RS-232 interface and obtain barometric pressure readings in real time. This application note will present the hardware set-up, a general program flow and a Quick Basic programming example necessary to utilize the SMRTBAR01 and SMRT-EB interface module as a highly accurate computer controlled barometer.

NECESSARY HARDWARE

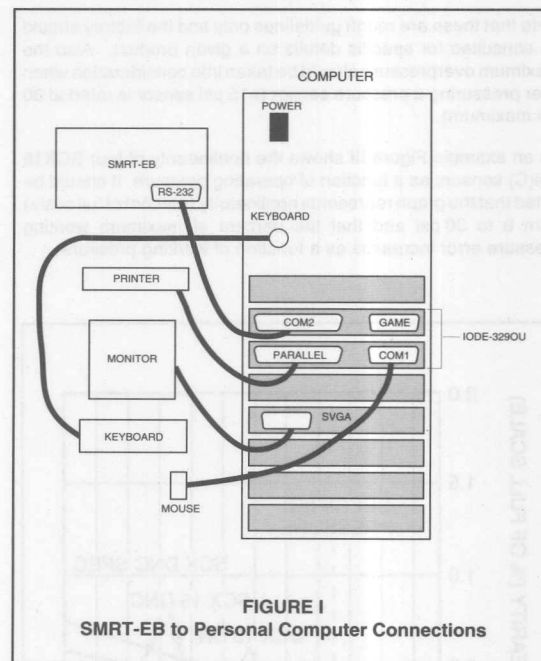
- Computer system with RS-232 serial port
- SenSym SMRT-EB interface module
- SenSym SMRTBAR01 pressure sensor
- RS-232 cable (Included in the standard SMRT-EB kit)
- 9V AC adaptor or 9V battery (Included in the standard SMRT-EB kit)

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SYSTEM SET-UP

The following example utilizes an IBM compatible computer with a 486 microprocessor and an IODE-3290U add-on card loaded into slots 2 and 3 of the computer add-on card cage. The IODE-3290U contains 2 serial (RS-232) ports, 1 parallel port, and 1 game port. Each of the serial ports has a unique connector type and a unique address, which on most serial add-on cards is selectable. One of the serial connections is accessible through a DB9P connector, which for this example has been designated as the COM1 address. The second serial connection is accessible through a DB25P connector, which is set as the COM2 address. See Figure I for a diagram of the back of the computer.



In this example, a mouse was connected to the DB9P/COM1 port so the SMRT-EB interface module will be connected to the DB25P/COM2 serial connector using the DB25P to DB25S cable (the longer of the two cables provided). If needed, the COM1 port can be used for the SMRT-EB by simply adding the DB25P to DB9S adaptor cable (the shorter of the two cables provided) and then using the combined cable to connect the SMRT-EB to the computer. See Figure I for the cable connections.

Now configure the SMRT-EB for the correct DIP switch and jumper settings. Figure II shows a layout of the SMRT-EB interface module. The DIP switch baud rate configuration and the jumper configuration will vary depending on the type of computer system and serial add-on card being used. For our example, the SMRT-EB is to be configured for remote use, a baud rate of 4800, 8 data bits and RTS (request to send) handshake. The DIP switch and jumper settings are as follows:

DIP Switch	1	2	3	4	5	6
	X	X	X	OFF	ON	OFF
X = Don't care						
Jumpers	P1	No jumper	8 data bits			
	P2	No jumper	Even parity			
	P3	No jumper	Disable parity			
	P4	No jumper	No DTR			
	P5	Jumper	RTS handshake			

Power can be supplied to the SMRT-EB interface module by either inserting a 9V battery into the battery holder or connecting the 9V AC adaptor, which comes with the SMRT-EB, to the SMRT-EB and a standard 110V AC outlet.

Once power is applied the SMRT-EB interface module is ready to be controlled through the computer using the software flow which follows.

SOFTWARE FLOW

In most applications the SMRT-EB barometer will not be the only instrument interfacing to the computer I/O bus. For this reason, it is best to design a software subprogram which allows for the system programmer to call for information from the SMRT-EB at any time within the main program. The following is a general description of the SMRT-EB operation, the flow of a subprogram which controls the SMRT-EB, and a copy of an actual main and subprogram combination which control the SMRT-EB barometer and generate a printout of the outputs gathered.

The SMRT-EB is designed to accept a command and generate a character output string. The format of the output string is as follows:

<command (echoed)><space><response><CR><LF>

There are a total of fourteen possible remote mode commands available for the SMRT-EB, a full list is available in the documentation which accompanies the SMRT-EB kit. In our application we will be using only six of these commands.

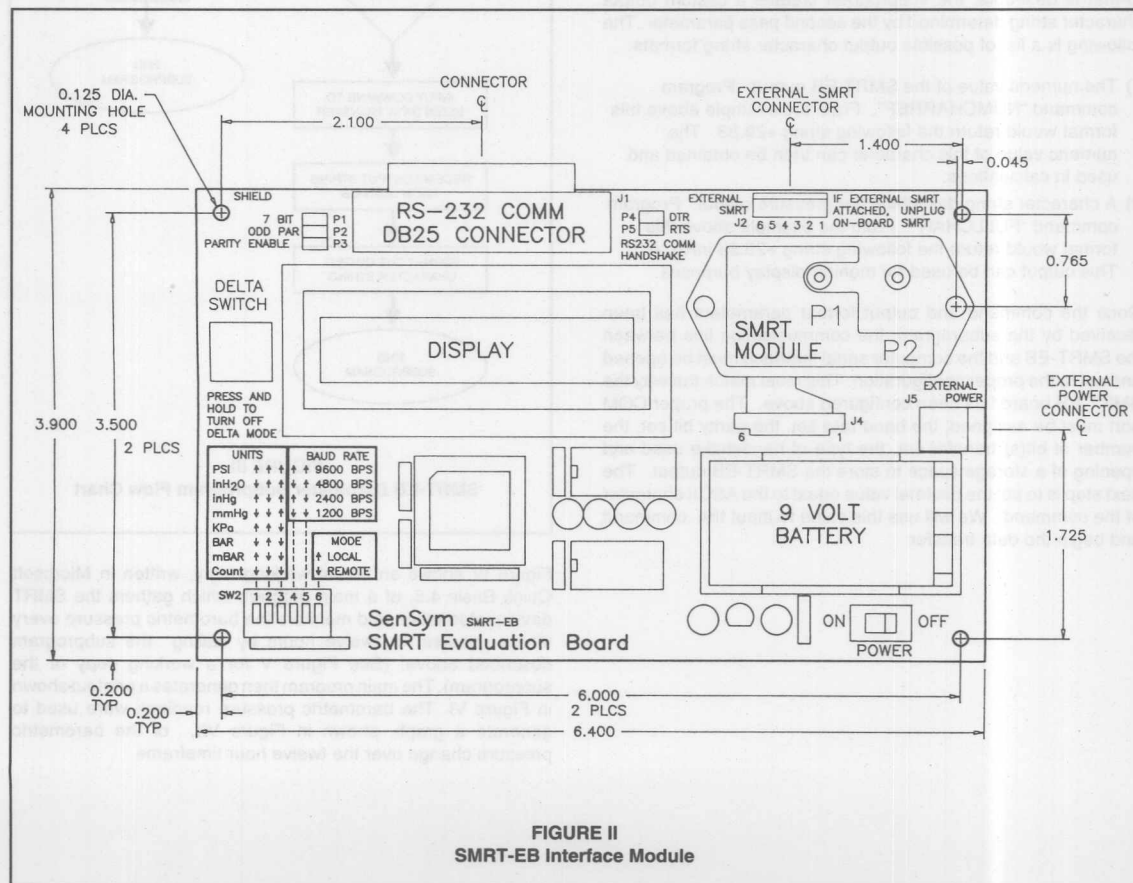


FIGURE II
SMRT-EB Interface Module

The subprogram to control the SMRT-EB barometer will pass two parameters and return one parameter. The first parameter to be passed to the subprogram is the command to the SMRT-EB. The following is a list of the possible command selections and what their character output string represents:

Program Command	SMRT-EB Command	Output Representation
1) INCHMERCPRES	3	Pressure in In. Hg
2) PORTASSIGN	A	SMRT sensor pressure port assignments
3) MODEL#	M	Model of the SMRT sensor
4) SETNORMMD	N	Sets SMRT-EB to normal mode
5) PRESSRANGE	R	Calibrated pressure range of the SMRT sensor
6) SERIAL#	S	SMRT sensor serial number

The second parameter to be passed to the subprogram is a parameter which determines the output format of the information returned from the subprogram. Shown below is an example of a standard output from the SMRT-EB in the format shown above.

Ex. 3 +29.83 inHg, A<CR><LF>

Because not all of the information given in the standard output format is desirable, the subprogram creates a custom output character string determined by the second pass parameter. The following is a list of possible output character string formats:

- 1) The numeric value of the SMRT-EB output. Program command "NUMCHARREF". From the example above this format would return the following string +29.83. The numeric value of this character can then be obtained and used in calculations.
- 2) A character string describing the pressure output. Program command "FULLCHAR". From the example above this format would return the following string +29.83 inHg, A. This output can be used for monitor display purposes.

Once the command and output format parameters has been received by the subprogram, the communication line between the SMRT-EB and the computer serial interface must be opened and set to the proper configuration. This must match the way the SMRT-EB board has been configured above. The proper COM port must be assigned, the baud rate set, the parity bit set, the number of bit(s) transfer set, the type of handshake used and opening of a storage space to store the SMRT-EB output. The next step is to set the decimal value equal to the ASCII character of the command. We will use this value to input the command and begin the data transfer.

Once the data transfer has started we will examine the decimal value of each ASCII output character individually, and store only the ASCII characters, but not the ASCII codes (CR and LF), into our output variable until the end of the output string, the LF, has been detected. Once the output string has been gathered the string is truncated to the desired output format. This truncated output character string is assigned to the output variable SMRTREAD\$ and returned to the main program. A flow chart describing the flow just described above is shown in Figure III.

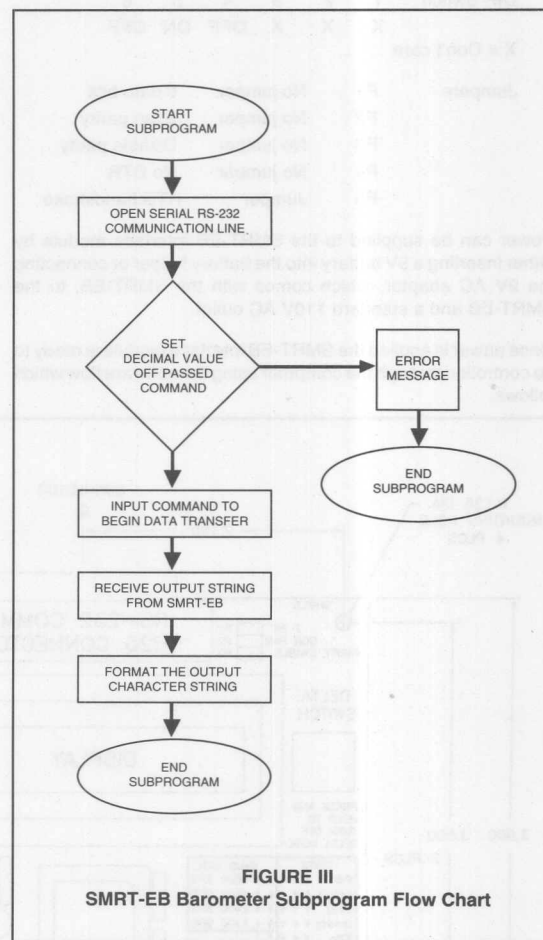


Figure IV shows an actual working copy, written in Microsoft Quick Basic 4.5, of a main program which gathers the SMRT device information and monitors the barometric pressure every fifteen minutes for twelve hours by calling the subprogram described above, (See Figure V for a working copy of the subprogram). The main program then generates a printout shown in Figure VI. The barometric pressure readings were used to generate a graph, shown in Figure VII, of the barometric pressure change over the twelve hour timeframe.


```

' *****
' ** MAIN PROGRAM **
' *****
DECLARE SUB SMRTEBBAROMETER (OUTPUTMODE$, CHARACTERTYPE$, SMRTREAD$)
DIM BARP!(100)
CLS 'MAKE SURE THE SCREEN IS CLEARED
'
' MAKE SURE THE BAROMETER IS IN THE NORMAL MEASUREMENT MODE
CALL SMRTEBBAROMETER("SETNORMMD", "FULLCHAR", SMRTREAD$)
'
' GET THE MODEL # OF THE SMRT SENSOR
CALL SMRTEBBAROMETER("MODEL#", "FULLCHAR", SMRTREAD$)
MODELNUM$ = SMRTREAD$
'
' GET THE SERIAL # OF THE SMRT SENSOR
CALL SMRTEBBAROMETER("SERIAL#", "FULLCHAR", SMRTREAD$)
SERIALNUM$ = SMRTREAD$
'
' GET THE SMRT SENSOR PORT ASSIGNMENTS
CALL SMRTEBBAROMETER("PORTASSIGN", "FULLCHAR", SMRTREAD$)
PORTASS$ = SMRTREAD$
'
' GET THE SMRT SENSOR PRESSURE RANGE
CALL SMRTEBBAROMETER("PRESSRANGE", "FULLCHAR", SMRTREAD$)
PRESRNG$ = SMRTREAD$
'
' MAKE AN INITIAL BAROMETRIC PRESSURE READING AND RETURN THE
' FULL OUTPUT STRING TO BE PRINTED
CALL SMRTEBBAROMETER("INCHMERCPRS", "FULLCHAR", SMRTREAD$)
FULLBAPRES$ = SMRTREAD$
'
' MAKE AN INITIAL BAROMETRIC PRESSURE READING AND RETURN THE
' NUMERIC VALUE OF THE SMRT OUTPUT
CALL SMRTEBBAROMETER("INCHMERCPRS", "NUMCHARREF", SMRTREAD$)
BAPRESNUM! = VAL(SMRTREAD$)
'
' PRINT THE SMRT INFORMATION AND INITIAL READINGS
LPRINT "YOU ARE USING A "; MODELNUM$; " SENSOR IN YOUR SMRT-EB"
LPRINT "THE SERIAL NUMBER OF THIS SENSOR IS "; SERIALNUM$
LPRINT "THE PRESSURE RANGE OF THIS SENSOR IS "; PRESRNG$
LPRINT "THE PRESSURE PORT ASSIGNMENTS OF THIS SENSOR IS "; PORTASS$
LPRINT
LPRINT "THE INITIAL BAROMETRIC OUTPUT IN FULL FORM IS "; FULLBAPRES$
LPRINT "THE INITIAL BAROMETRIC OUTPUT IN NUMERIC FORM IS "; BAPRESNUM!
LPRINT
'
' NOW USE THE BAROMETER TO MONITOR THE ATMOSPHERIC PRESSURE EVERY 15 MINUTES
' FOR 12 HOURS. STORE THE DATA SO IT CAN BE USED LATER. SEE FIGURE 6
' FOR A GRAPH OF THE OUTPUT
LPRINT
LPRINT "THE DATE IS "; DATE$
LPRINT
FOR i% = 1 TO 48
' GET THE NUMERIC VALUE OF THE CHARACTER STORE IT FOR GRAPHING.
CALL SMRTEBBAROMETER("INCHMERCPRS", "NUMCHARREF", SMRTREAD$)
BARP!(i%) = VAL(SMRTREAD$)
'
' GET THE FULL CHARACTER OUTPUT FOR PRINTING PURPOSES
CALL SMRTEBBAROMETER("INCHMERCPRS", "FULLCHAR", SMRTREAD$)
LPRINT "THE BAROMETRIC PRESSURE AT "; TIME$; " IS "; SMRTREAD$
SLEEP 900
NEXT i%
END

```

FIGURE IV
Main Program

```

/ *****
/ ** SMRT-EB BAROMETER SUBPROGRAM **
/ *****
SUB SMRTBBAROMETER (OUTPUTMODE$, CHARACTERTYPES$, SMRTREAD$)
/ *****
/ THIS SUBPROGRAM CONTROLS AND READS THE SMRT-EB INTERFACE
/ MODULE FOR USE AS A BAROMETER
/
/VARIABLES RECEIVED ARE:
/ OUTPUTMODE$ = CONTROLS WHICH DISPLAY/OUTPUT MODE THE SMRT-EB
/ WILL BE IN. THE POSSIBLE SETTINGS ARE:
/ "INCHMERCIPRES" - OUTPUT PRESSURE IN INCHES OF MERCURY (inHg).
/ "PORTASSIGN" - OUTPUT THE SMRT PRESSURE PORT ASSIGNMENTS.
/ "MODEL#" - OUTPUT THE MODEL NUMBER OF THE SMRT SENSOR.
/ "SETNORMMD" - SETS THE EB BOARD INTO THE NORMAL PRESSURE
/ OUTPUT MODE. REMOVES THE DELTA MODE.
/ "PRESSRANGE" - OUTPUT THE PRESSURE RANGE OF THE SMRT
/ PRESSURE SENSOR.
/ "SERIAL#" - OUTPUT THE SERIAL NUMBER OF THE SMRT SENSOR.
/ CHARACTERTYPES$ = CONTROLS WHAT FORMAT THE OUTPUT WILL BE IN. THE POSSIBLE
/ SETTINGS ARE:
/ "NUMCHARREF" - RETURN A CHARACTER WHICH REPRESENTS THE
/ NUMERIC VALUE OF THE SMRT OUTPUT.
/ "FULLCHAR" - RETURN THE FULL SMRT OUTPUT CHARACTER STRING.
/
/VARIABLES RETURNED ARE:
/ SMRTREAD$ = THE CHARACTER OUTPUT OF THE EB BOARD DETERMINED BY THE
/ OUTPUTMODE$ AND CHARACTERTYPES$ INPUTS.
/
/OTHER VARIABLES ARE:
/ SMRTVAL% = NUMERIC VALUE THAT IS THE ASCII CODE FOR EACH INDIVIDUAL
/ CHARACTER OF THE OUTPUT STRING OF THE SMRT SENSOR.
/ NSMRTOUTPUT$ = STORES THE MODIFIED SMRT OUTPUT CONTAINING ONLY
/ THE DESIRED CHARACTERS OF THE OUTPUT STRING.
/ COMANDECVAl% = DECIMAL VALUE CORRESPONDING TO THE REMOTE COMMAND
/ WHICH CONTROLS THE SMRT EB OUTPUT MODE.
/ INDSMRTOUTPUT$ = STORES EACH INDIVIDUAL CHARACTER AS THEY ARE READ FROM THE
/ SMRT SENSOR.
/ NUMCHAR% = THE NUMBER OF CHARACTERS WHICH ARE IN THE NSMRTOUTPUT$ STRING.
/ *****
/ OPEN THE COMMUNICATION LINE TO THE RS-232 SERIAL PORT LOCATED AT COM2
/ SET THE BAUD RATE TO 4800
/ DISABLE PARITY
/ SET FOR 8 BIT DATA TRANSFER
/ SET FOR 1 STOP BIT
/ OPEN A STORAGE SPACE FOR DATA AT #1
OPEN "COM2:4800,N,8,1" FOR RANDOM AS #1
/
SMRTVAL% = 0 'INITIALIZE VARIABLES.
NSMRTOUTPUT$ = ""
/
SELECT CASE OUTPUTMODE$ 'SET THE OUTPUT MODE.
CASE "INCHMERCIPRES"
COMANDECVAl% = 51 'SET DECIMAL VALUE FOR REMOTE COMAND 3.
CASE "PORTASSIGN"
COMANDECVAl% = 65 'SET DECIMAL VALUE FOR REMOTE COMAND A.
CASE "MODEL#"
COMANDECVAl% = 77 'SET DECIMAL VALUE FOR REMOTE COMAND M.
CASE "SETNORMMD"
COMANDECVAl% = 78 'SET DECIMAL VALUE FOR REMOTE COMAND N.
CASE "PRESSRANGE"
COMANDECVAl% = 82 'SET DECIMAL VALUE FOR REMOTE COMAND R.
CASE "SERIAL#"
COMANDECVAl% = 83 'SET DECIMAL VALUE FOR REMOTE COMAND S.
CASE ELSE
CLS
PRINT "INCORRECT OUTPUTMODE$ PASS PARAMETER"
STOP
END SELECT
PRINT #1, CHR$(COMANDECVAl%); 'SEND COMMAND TO BEGIN DATA TRANSFER
/
DO UNTIL SMRTVAL% = 10 'GATHER OUTPUT ONE CHARACTER AT A TIME
'UNTIL THE END (LINEFEED) IS DETECTED.
/
INDSMRTOUTPUT$ = INPUT$(1, #1) 'STORE EACH INDIVIDUAL CHARACTER.
/
SMRTVAL% = ASC(INDSMRTOUTPUT$) 'DETERMINE THE DECIMAL VALUE OF
'THE CHARACTER.
/
SELECT CASE SMRTVAL% 'STORE ONLY VALID OUTPUT CHARACTERS.
CASE 32 TO 126
NSMRTOUTPUT$ = NSMRTOUTPUT$ + INDSMRTOUTPUT$ 'BUILD OUTPUT
'String.
CASE ELSE
'DO NOT SAVE THIS CHARACTER
END SELECT
/
LOOP
CLOSE #1 'CLOSE THE OUTPUT DATA STORAGE FILE.
NUMCHAR% = LEN(NSMRTOUTPUT$) 'DETERMINE THE LENGTH OF THE
'OUTPUT STRING.
/
SELECT CASE CHARACTERTYPES$
CASE "NUMCHARREF" 'SELECT THE CHARACTER OUTPUT FORMAT.
SMRTREAD$ = MID$(NSMRTOUTPUT$, 3, 8)
CASE "FULLCHAR"
SMRTREAD$ = MID$(NSMRTOUTPUT$, 3, NUMCHAR%)
END SELECT
END SUB

```

FIGURE V
SMRT-EB Barometer Subprogram

YOU ARE USING A SMRTBARO1 SENSOR IN YOUR SMRT-EB
 THE SERIAL NUMBER OF THIS SENSOR IS Serial No.000102
 THE PRESSURE RANGE OF THIS SENSOR IS 20 to 32 inHg
 THE PRESSURE PORT ASSIGNMENTS OF THIS SENSOR IS P1 +, P2 Unused

THE INITIAL BAROMETRIC OUTPUT IN FULL FORM IS +29.83 inHg,A
 THE INITIAL BAROMETRIC OUTPUT IN NUMERIC FORM IS 29.83

THE DATE IS 02-05-1992

THE BAROMETRIC PRESSURE AT 16:27:31 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 16:42:32 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 16:57:32 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 17:12:32 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 17:27:32 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 17:42:33 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 17:57:33 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 18:12:33 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 18:27:34 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 18:42:34 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 18:57:34 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 19:12:35 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 19:27:35 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 19:42:35 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 19:57:36 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 20:12:36 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 20:27:36 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 20:42:36 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 20:57:37 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 21:12:37 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 21:27:37 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 21:42:38 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 21:57:38 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 22:12:38 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 22:27:39 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 22:42:39 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 22:57:39 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 23:12:40 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 23:27:40 IS	+29.85	inHg,A
THE BAROMETRIC PRESSURE AT 23:42:40 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 23:57:41 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 00:12:42 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 00:27:42 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 00:42:42 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 00:57:42 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 01:12:43 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 01:27:43 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 01:42:43 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 01:57:44 IS	+29.84	inHg,A
THE BAROMETRIC PRESSURE AT 02:12:44 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 02:27:44 IS	+29.83	inHg,A
THE BAROMETRIC PRESSURE AT 02:42:44 IS	+29.82	inHg,A
THE BAROMETRIC PRESSURE AT 02:57:45 IS	+29.82	inHg,A
THE BAROMETRIC PRESSURE AT 03:12:45 IS	+29.82	inHg,A
THE BAROMETRIC PRESSURE AT 03:27:45 IS	+29.82	inHg,A
THE BAROMETRIC PRESSURE AT 03:42:46 IS	+29.82	inHg,A
THE BAROMETRIC PRESSURE AT 03:57:46 IS	+29.81	inHg,A
THE BAROMETRIC PRESSURE AT 04:12:46 IS	+29.81	inHg,A

FIGURE VI
 Main Program Information Printout

SMRT-EB Barometric pressure readings taken every 15 minutes for a 12 hour timeperiod.

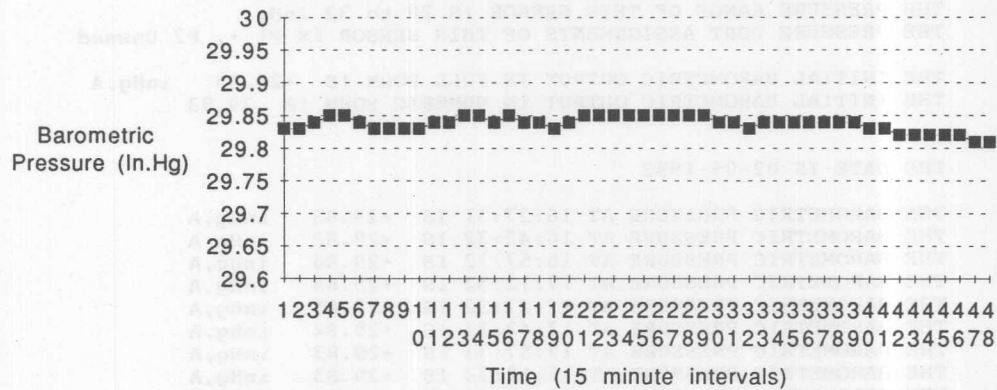


FIGURE VII
SMRT-EB Barometric Pressure Output Graph

CONCLUSION

A high accuracy computer controlled barometer can be quite easily designed by simply interfacing the SMRT-EB interface module, a SMRTBAR01 sensor a personal computer and writing some simple interface control software.

Simple Pressure Port Modifications for the SCX Series Sensor

By Duane Tandeske

INTRODUCTION

The SCX series are temperature compensated and calibrated pressure sensors that are packaged in a 30% glass filled Nylon housing. Pressure is applied to the sensor via two 0.190 inch barbed pressure fittings. The package is designed to be used with 0.25 inch flexible tubing. This application note will discuss a technique to modify the pressure ports to accommodate other pressure fittings and/or reduce the minimum vertical clearance necessary to use the sensor in a card rack.

BONDABLE JUNCTIONS

A family of bondable junction blocks are available from Value Plastics which allows simple modification of the SCX pressure ports. Each block is a plastic cube with 0.190 inch diameter holes drilled into two or more sides. The junction blocks are available in ABS plastic or polysulfone. Value Plastics address and phone number is:

Value Plastics
33050 Eastbrook Drive
Fort Collins, CO
80525
(303) 223-8306

Also available from Value plastics are a number of pressure fittings that can be used with the junction blocks:

- Threaded pressure ports - #10 - 32 to $\frac{1}{8}$ - 27 NPT (high pressure)
- Straight and right angle barb fittings - $\frac{1}{16}$ ID to $\frac{1}{8}$ ID (low to medium pressure)
- Male and Female Luer fittings (medical)

Note: Value Plastics will custom bond assemblies for a minimal cost, minimum order of 100 assemblies.

The combination of junction block and pressure fittings can be used to modify the SCX package as follows:

- Reduce package height (1" board spacing)
- Reduce working volume
- Threaded pressure port for high pressure
- Design a flow through port
- Convert to any tube size used in the system

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SSAN-37

PROCEDURE

The SCX pressure port modification is a simple procedure. The pressure ports are removed as shown in Figure I. The ports can be removed with a pair of wire cutters or cut off with a sharp blade.

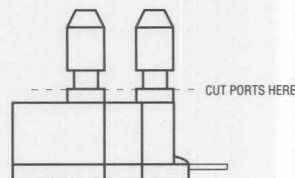


FIGURE I

Next, assemble the bondable junction and pressure fitting of choice. After the assembly has cured, bond it to the SCX sensor. The junction block will typically have a slight press fit over the stub of the removed SCX pressure port. Figure II shows an example of two, right angle, $\frac{1}{16}$ inch barb fittings.

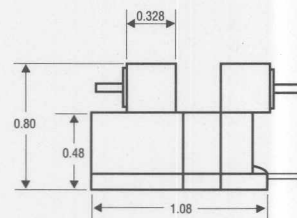


FIGURE II

Permabond #268 quick setting adhesive is recommended to bond the assemblies. This is available from:

Permabond International
480 S. Dean Street
Englewood, NJ
07631-9990
(201) 567-9494

CONCLUSION

Using bondable junctions is a very cost effective simple means of customizing the SCX pressure ports to fit the application. The parts cost for the modification of one port is typically less than \$0.50.

SOLID STATE SENSORS

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FIGURE 1

test, activate the bonding function and measure the bond strength. After the assembly has cooled, return to the SCC sensor. The function that will provide a high degree of coverage of the sensor SCC pressure port. Figure 1 shows an example of two right angles, as high as 180°.



FIGURE 2

Figure 2 shows a cross section of the sensor package. The sensor package is shown in cross section.

Standard dimensions
and 5.0mm pins
(pin-to-pin)
(pin-to-pin)
(pin-to-pin)

CONCLUSION

The solid state sensor is a very low cost, effective single channel sensor. The solid state sensor is a very low cost, effective single channel sensor. The solid state sensor is a very low cost, effective single channel sensor.

Simple Pressure Port
Modifications for the SCC
Series Set 201

By James T. Johnson

INTRODUCTION

The SCC series is a solid state sensor that is designed to be used in a wide range of applications. The sensor is designed to be used in a wide range of applications. The sensor is designed to be used in a wide range of applications.

BONDABLE FUNCTIONS

A variety of bondable functions are available from the SCC series. The bondable functions are available from the SCC series. The bondable functions are available from the SCC series.

Value Pressure
2.000 Bar/100 PSI
For Contact: C2
20001
(200) 224-8200

Also available from V. The sensor is a solid state sensor. The sensor is a solid state sensor. The sensor is a solid state sensor.

1. Threaded for wide bore - 1/8" - 1/2" to 1/2" to 1/2"
2. Straight and right angle for wide bore - 1/8" - 1/2" to 1/2" to 1/2"
3. Fine to thick in bore - 1/8" - 1/2" to 1/2" to 1/2"
4. Mini size for wide bore - 1/8" - 1/2" to 1/2" to 1/2"

Mini Value Pressure - 2.000 Bar/100 PSI for a variety of applications.

The sensor is a solid state sensor. The sensor is a solid state sensor. The sensor is a solid state sensor.

1. Threaded for wide bore - 1/8" - 1/2" to 1/2" to 1/2"
2. Straight and right angle for wide bore - 1/8" - 1/2" to 1/2" to 1/2"
3. Fine to thick in bore - 1/8" - 1/2" to 1/2" to 1/2"
4. Mini size for wide bore - 1/8" - 1/2" to 1/2" to 1/2"

SOLID STATE SENSORS

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SECTION 8

APPENDICES

SECTION TABLE OF CONTENTS

Definition of Terms

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SOLID STATE SENSORS

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Definition of Terms

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GENERAL TERMS

Absolute Pressure: Pressure measured relative to a vacuum. Usually expressed in pounds per square inch absolute (psia).

Differential Pressure: The pressure difference measured between two pressure sources. Usually expressed in pounds per square inch differential (psid). When one source is a perfect vacuum, the pressure difference is called *absolute pressure*. When one source is the local ambient, the pressure is called *gage pressure*.

Differential Pressure Transducer: A device that measures the differential pressure between two pressure sources piped to its inputs.

Gage Pressure: Pressure measured relative to ambient pressure (psig).

Barometric Pressure Transducer: An absolute pressure transducer measuring the local ambient pressure.

Altimetric Pressure Transducer: A barometric pressure transducer used to determine altitude from the pressure altitude profile.

Vacuum: A perfect vacuum is the absence of gaseous fluid.

Vacuum Range: The range of absolute pressures between a perfect vacuum (0 psia) and one standard atmosphere (14.697 psia).

Vacuum Transducer: A transducer scaled for pressure measurement in the vacuum range. This is usually an absolute transducer, but sometimes a gage transducer.

TRANSDUCER PARAMETERS

Operating Pressure Range: The specified range over which a transducer is intended to measure, specified by the upper and lower limits.

Span: The arithmetic difference in transducer output signal measured at the specified minimum and maximum operating pressures.

Sensitivity: The ratio of output signal voltage change to the corresponding input pressure change. Sensitivity is determined by computing the ratio of span to the specified input pressure range.

Reference Temperature: The temperature used as reference in measuring transducer errors.

Full-Scale: The algebraic difference between endpoints. Where one endpoint is actual offset voltage and the other endpoint is the upper limit of the range.

Reference Pressure: The pressure used as a reference in measuring transducer errors.

Offset Voltage: The transducer output signal obtained when the reference pressure is applied.

Over-Pressure-Maximum: The maximum *normal mode* (measured) pressure that can be applied without changing the transducer's performance or accuracy beyond the specified limits. This would be applied to either port of a differential transducer. This is also called PROOF PRESSURE.

Common-Mode Pressure-Maximum: The maximum pressure that can be applied to both ports simultaneously of a differential transducer.

Burst Pressure: The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.

GENERAL ERROR TERMS

Best Straight Line (BSL): The best straight line chosen such that the true transducer response curve contains three points of equal maximum deviation.

Error Band: The deviation of transducer response from its BSL, defined by lines on either side of its BSL and including the maximum deviation measured for a *given normal mode* or *common mode* error.

Temperature Coefficient (TC): The *error band* resulting from maximum deviation of a transducer output parameter (such as *offset* or *span*) as temperature is varied from 25°C to any other temperature within the specified range. It is usually measured in V/°C and divided by *sensitivity* to express the magnitude of the *error band* in psi/°C.

Repeatability: The *error band* expressing the ability of the transducer to reproduce an output signal parameter (such as *offset* or *span*), at specified pressures and temperature, after exposure to any other pressure and temperature within the specified range.

Stability: The *error band* expressing the ability of a transducer to maintain the value of an output parameter (such as *offset* or *span*) with constant temperature and pressure inputs.

Definition of Terms (Cont.)

Interchangeability: The *error band* defined by the maximum signal deviation obtained when a transducer is replaced by any other transducer of the same type with equivalent pressure inputs and temperature ranges.

Normal Mode Error: An error that is a function of (and usually assumed to be proportional to) the major input variable (input pressure). For SenSym transducers, all *span errors* are normal mode errors.

Common-Mode Error: An error that is independent of the major input variable (input pressure). For SenSym transducers, all *offset errors* are common-mode errors.

Auto-Referencing: A technique for eliminating errors by sampling one or more reference pressures, then correcting the output signal function.

OFFSET ERROR TERMS (COMMON-MODE)

Offset Error: The *common-mode error band* defined by the maximum deviation of *offset voltage* from its specified value. It may include calibration, temperature coefficient, repeatability and stability errors.

Offset Calibration: The *error band* defined by the maximum error in calibrating the *offset voltage*.

Offset Temperature Coefficient: The *error band* defined by the maximum deviation in *offset voltage* as the temperature is varied from 25°C to any other temperature within the specified range.

Offset Repeatability: The *error band* expressing the ability of the transducer to reproduce the *offset voltage*, measured at 25°C, after exposure to any other temperature and pressure within the specified range.

Offset Stability: The *error band* expressing the ability of the transducer to maintain the *offset voltage* with constant pressure and temperature.

SPAN ERROR TERMS (NORMAL MODE)

Span Error: The *normal mode error band* defined by the maximum deviation of *span* from its specified value. It may include sensitivity calibration temperature, coefficient, linearity, hysteresis, repeatability and stability deviations.

Sensitivity Calibration: The *error band* defined by the maximum error in calibrating *sensitivity*.

Span Temperature Coefficient: The *error band* defined by the maximum deviation of the *span* as the temperature is varied from 25°C to any other temperature within the specified range. It is obtained by measuring output voltage change as pressure is varied from *reference* to maximum, dividing by the temperature excursion then by sensitivity to express the magnitude of the *error band* in psi.

Linearity: The maximum deviation of measured output at constant temperature (25°C) from "best straight line" determined by three points (offset pressure, full-scale pressure, and one-half full-scale pressure).

$$\left[V_{1/2 \text{ full-scale}} - \left\{ \left(\frac{V_{\text{full-scale}} - V_{\text{offset}}}{\text{full-scale pressure}} \right) \times (1/2 \text{ full-scale pressure}) + V_{\text{offset}} \right\} \right] \div 2 (V_{\text{full-scale}}) \times 100\%$$

where:

V = measured value for each device

Hysteresis of Pressure: The *error band* defined by the maximum deviation in output signal obtained when a specific pressure point is approached first with increasing pressure, then with decreasing pressure or vice versa at a constant temperature.

Span Repeatability: The *error band* expressing the ability of a transducer to reproduce its *span*, measured at 25°C, after exposure to any other pressure and temperature within the specified range.

Span Stability: The *error band* expressing the ability of the transducer to maintain the *span voltage* with pressure varied from minimum to maximum and temperature held constant.

OVERALL ACCURACY

Overall Accuracy-Calibrated: The combined *error band* relative to the BSL with forced reference unique to one specific transducer. It excludes offset and sensitivity calibration errors. It includes all other offset and span errors: temperature coefficient, repeatability, stability, linearity and hysteresis.

Overall Accuracy-Interchangeable: The combined *error band* relative to an ideal transducer response characteristic. It excludes stability errors because stability error is already included in specified calibration error. It includes all other offset and span errors: calibration, temperature coefficient, repeatability, linearity and hysteresis.

Most Probable Error: The *error band* obtained by computing the square root of the sum of the squares of all applicable errors specified for the transducer.

Worst-Case Error: The *error band* obtained by simple addition of all applicable errors specified for the transducer.

SOLID STATE SENSORS

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SECTION 9 PACKAGE OUTLINE DRAWINGS

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SOLID STATE SENSORS

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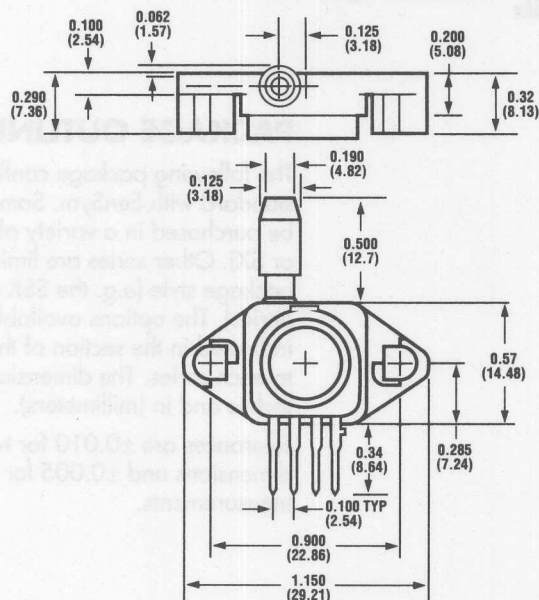
PACKAGE OUTLINE DRAWINGS

The following package configurations are standard with SenSym. Some sensor series can be purchased in a variety of packages (e.g. SCC or SX). Other series are limited to only one package style (e.g. the SSX or SCC "ISO" Series). The options available for each series are indicated in the section of this handbook specific to each series. The dimensions are given in inches and in (millimeters).

Tolerances are ± 0.010 for two decimal place dimensions and ± 0.005 for three decimal place measurements.

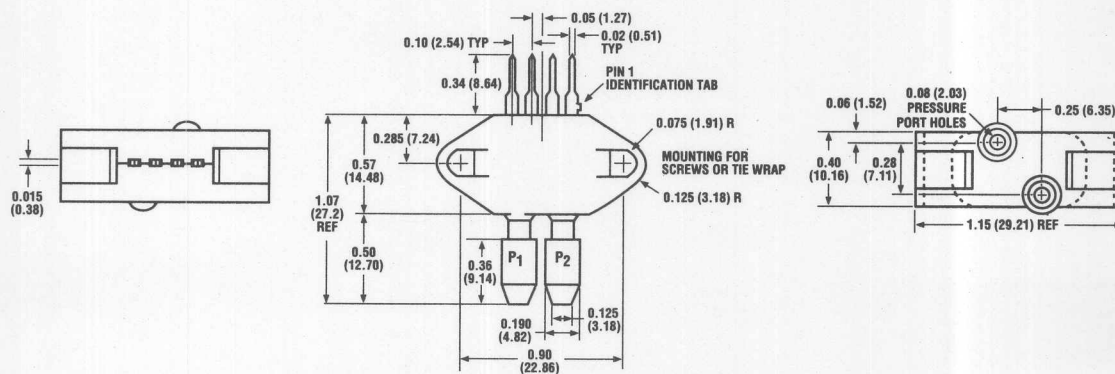
PACKAGE OUTLINES

1/2 N Package (N2)



Weight: 2.56 grams

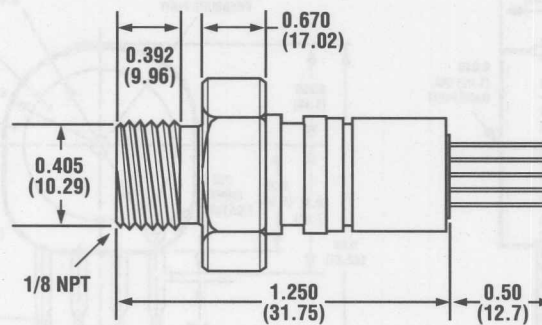
N Package



Weight: 4.5 grams

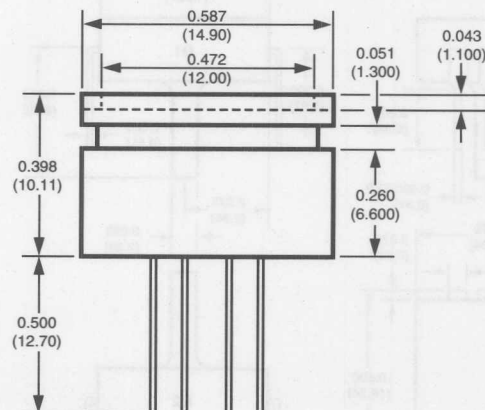
PACKAGE OUTLINES

SSC Package



Weight: 1 ounce

SS Cell Package

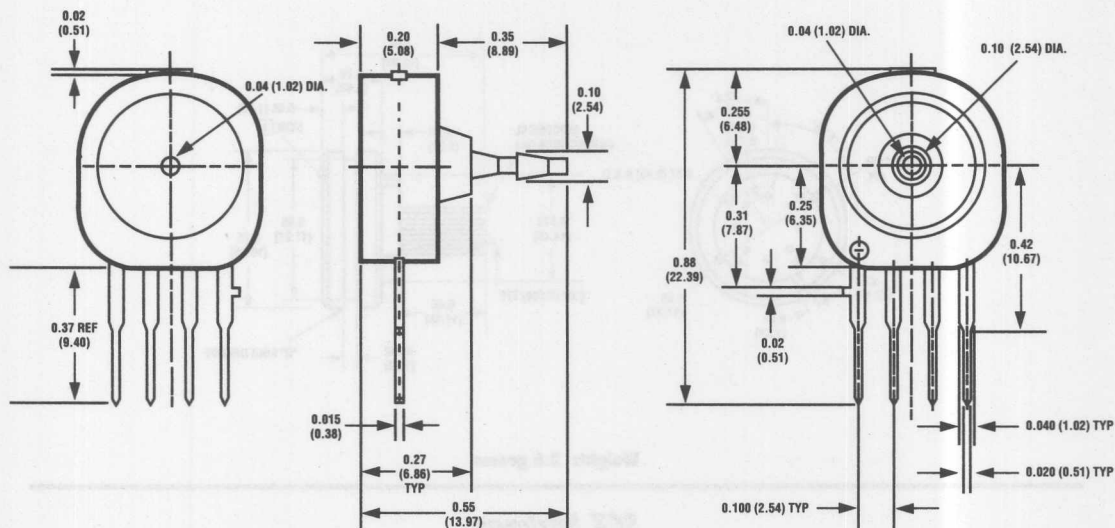


Weight: 0.5 ounce



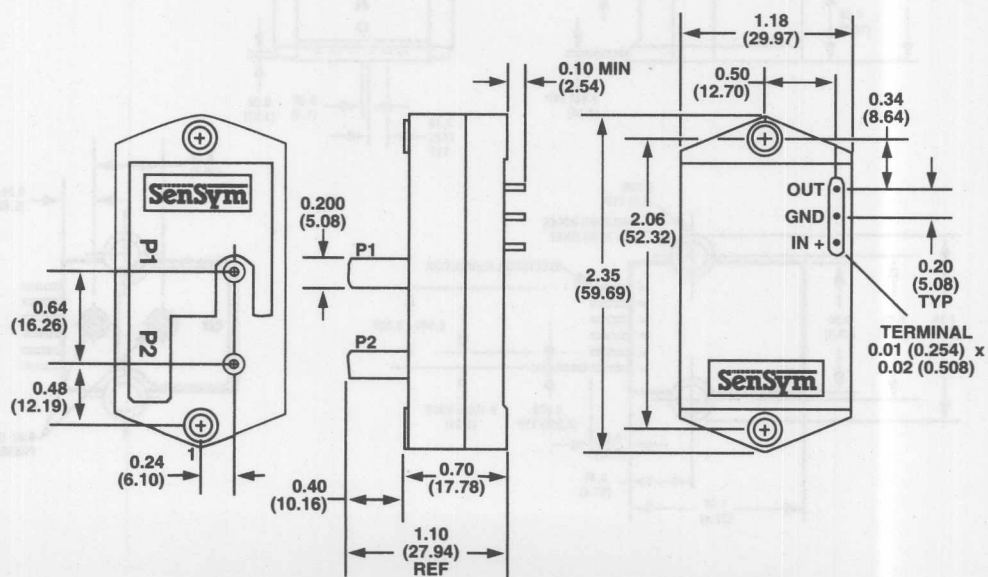
PACKAGE OUTLINES

DP1 Button Package



Weight: 1.1 gram

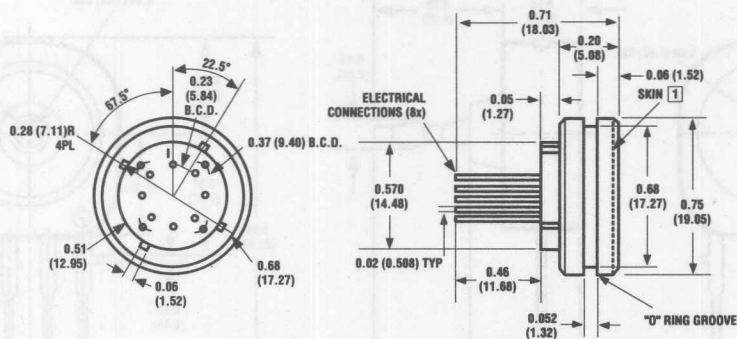
142SC Package



Weight: 22 grams

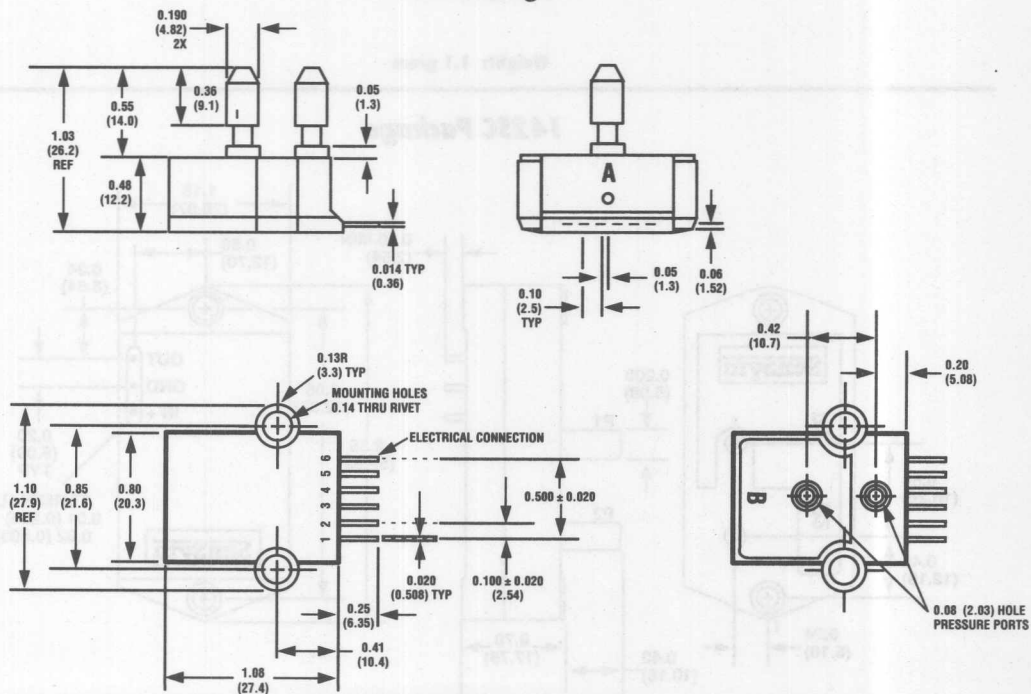
PACKAGE OUTLINES

SCC-ISO Package



Weight: 2.6 grams

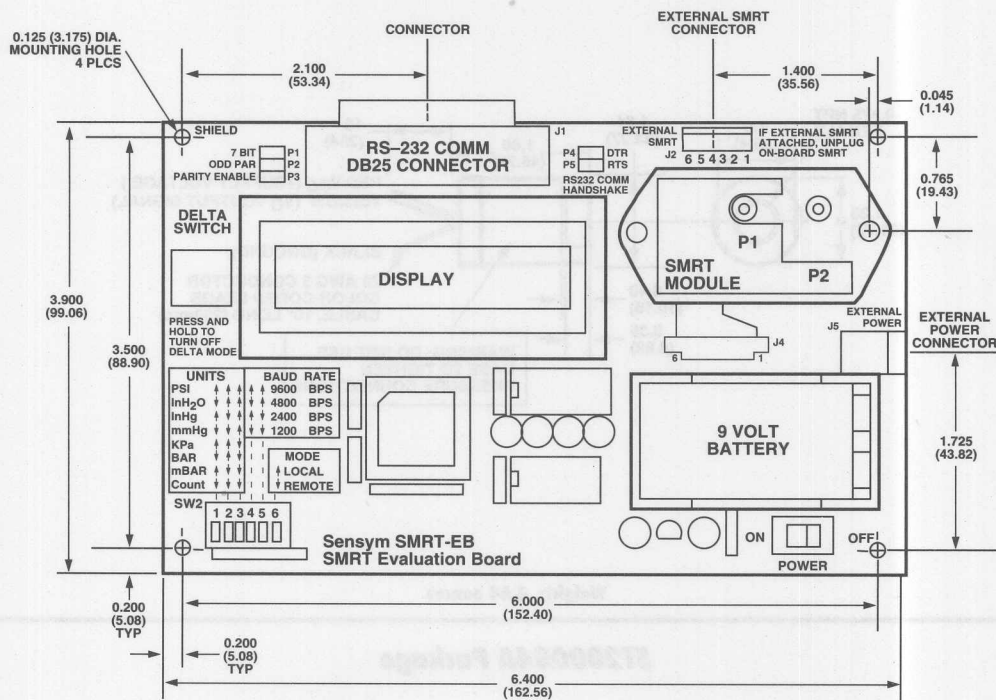
SCX Package



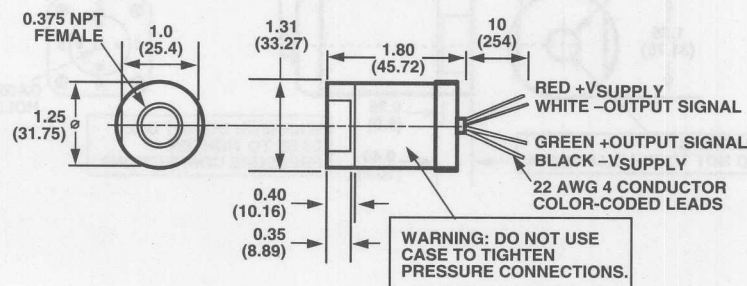
Weight: 5 grams

PACKAGE OUTLINES

SMRT-EB Evaluation Board



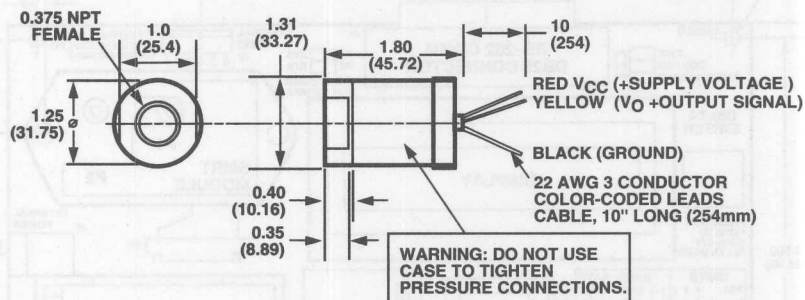
SSX Package



Weight: 3 ounces

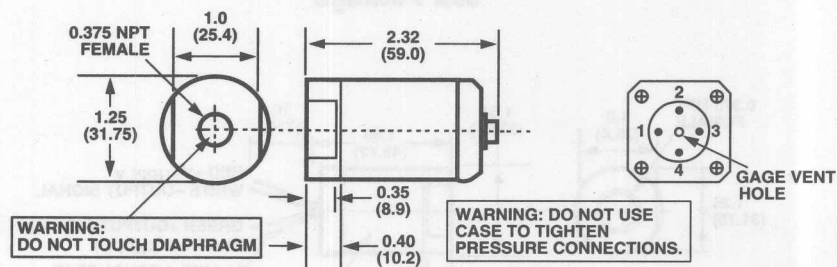
PACKAGE OUTLINES

ST2000 Package



Weight: 4.64 ounces

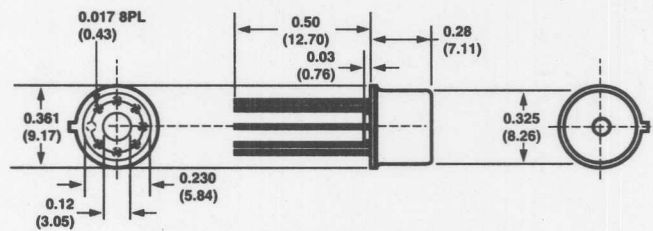
ST2000G4A Package



Weight: 4.64 ounces

PACKAGE OUTLINES

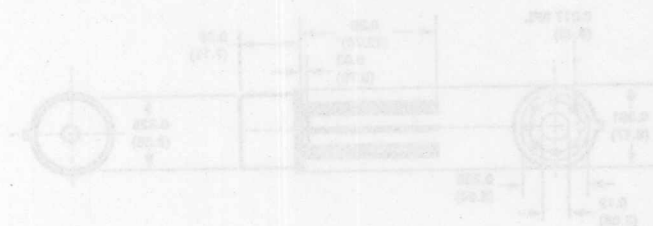
AH Package (T0-5)



Weight: 1.14 grams

SOLID STATE SENSORS

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Weight: 0.15 gms

SOLID STATE SENSORS

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SECTION 10 ACCESSORIES

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SOLID STATE SENSORS

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SENSYM'S ACCESSORIES

SCX Accessories

MOUNTING ACCESSORIES

DESCRIPTION	PART NUMBER
Xmas Tree Clip (200 ea)	SCXCLIP
6 Pin Right Angle Socket (100 ea)	SCXCNCT
Pressure Tubing Clamp (100 ea)	SCXSNP1

LX18XX Accessories

LX18XX (PX8) MATING CONNECTOR

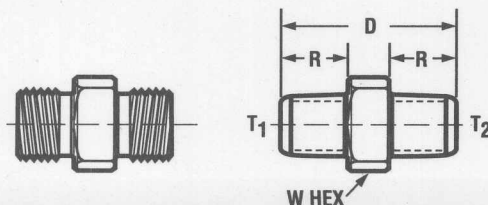
VENDOR	CONNECTOR#	MALE PIN#
Litton-Winchester Win-Com Series	59-03P1000	159-1018P
Waldon/Molex	03-09-2031	02-09-2103
Molex—without mounting ears	03-09-2032	—

SSX and ST Series Accessories

OPTIONAL PIPE FITTING DRAWINGS

SENSYM PART #	PARKER CAT. 420 PART #	NPT THREAD		W HEX	D		R	
		MALE T ₁	MALE T ₂		in.	mm	in.	mm
SFIT62	6-2MHN	3/8	1/8	3/4	1.27	32.30	0.56/0.38	14.2/9.7
SFIT64	6-4MHN	3/8	1/4	3/4	1.45	37.00	0.56	14.2

MALE HEX NIPPLE MHN

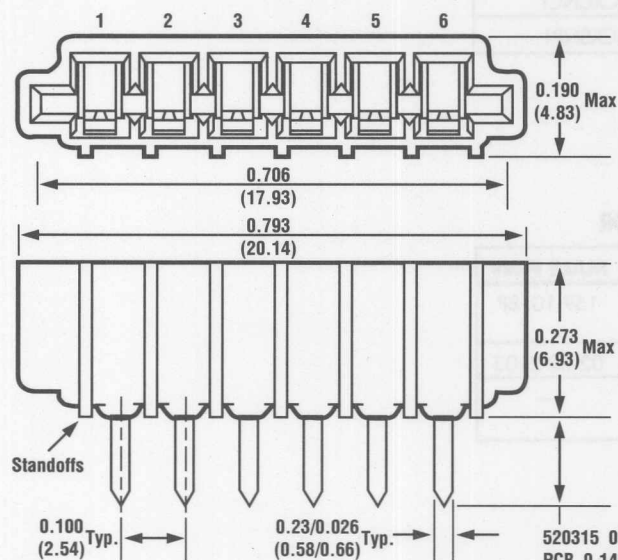


SENSYM'S ACCESSORIES

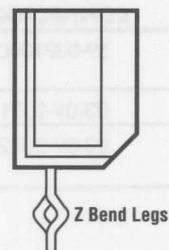
SMRT Accessories

FLEXIBLE CABLE CONNECTOR

AMP, Inc. P/N 520315-6



Vertical Cable
Entry for 0.062 (1.57)
and 0.093 (2.36)
Thick PC Boards



520315 0.062 (1.57)
PCB 0.140 ±0.010 (3.56±0.254)
520316 0.093 (2.36)
PCB 0.160 ±0.010 (4.06±0.254)

Reference Tables

SenSym

AREA OF CIRCLES IN FT ²			
Diam. in Inches	AREA Square Feet	Diam. in Inches	AREA Square Feet
1	.0054	30	4.909
1½	.0123	31	5.241
2	.0218	32	5.585
2½	.0341	33	5.940
3	.0491	34	6.305
3½	.0668	35	6.611
4	.0873	36	7.069
4½	.1105	37	7.467
5	.1364	38	7.876
5½	.1650	39	8.296
6	.1964	40	8.727
6½	.2305	41	9.168
7	.2673	42	9.621
7½	.3068	43	10.08
8	.3491	44	10.56
8½	.3940	45	11.04
9	.4418	46	11.54
9½	.4923	47	12.05
10	.5454	48	12.57
11	.6600	49	13.10
12	.7854	50	13.64
13	.9218	51	14.19
14	1.069	52	14.75
15	1.227	53	15.32
16	1.396	54	15.90
17	1.576	56	17.10
18	1.767	58	18.35
19	1.969	60	19.63
20	2.182	62	20.97
21	2.405	64	22.34
22	2.640	66	23.76
23	2.885	68	25.22
24	3.142	70	26.73
25	3.409	72	28.27
26	3.687	74	29.87
27	3.976	76	31.50
28	4.276	78	33.18
29	4.587	80	34.91

VOLUME EQUIVALENTS	
1 CU. FT. =	1728 Cu. In. 7.481 Gal. (U.S.) 28.317 Liters 28,317 Cu. Cm.
1 GAL. (U.S.) =	231 Cu. In. .1337 Cu. Ft. 3.785 Liters 3785 Cu. Cm.
1 LITER =	.0353 Cu. Ft. .2642 Gal. (U.S.) 1000 Cu. Cm.

SPECIFIC GRAVITIES OF GASES		
(BASED ON 68°F. AND 14.7 LBS. ABS.)		
ACETYLENE	C ₂ H ₂	.897
AIR	—	1.000
AMMONIA	NH ₃	.587
ARGON	A	1.378
BUTANE - N	C ₄ H ₁₀	2.390
BUTANE - ISO	(CH ₃) ₂ CH CH ₃	1.990
CARBON DIOXIDE	CO ₂	1.517
CARBON MONOXIDE	CO	.966
CHLORINE	Cl ₂	2.452
ETHANE	C ₂ H ₆	1.035
HELIUM	He	.138
HYDROGEN	H ₂	.070
METHANE	CH ₄	.553
NATURAL GAS	—	.665
		(Approx. Avg.)
NITRIC OXIDE	NO	1.035
NITROGEN	N ₂	.966
NITROUS OXIDE	N ₂ O	1.518
OXYGEN	O ₂	1.103
PROPANE	C ₃ H ₈	1.990
SULPHUR DIOXIDE	SO ₂	2.209

FLOW EQUIVALENTS							
1 Cu. Ft./Hr.		1 Cu. Ft./Min.		1 CC/Min.		1 CC/Hr.	
.0166	Cu. Ft./Min.	60	Cu. Ft./Hr.	60	CC/Hr.	.0167	CC/Min.
.4719	LPM	28.316	LPM	.000035	Cu. Ft./Min.	.0000005	Cu. Ft./Min.
28.316	LPH	1699	LPH	.0021	Cu. Ft./Hr.	.00003	Cu. Ft./Hr.
471.947	CC/Min.	28317	CC/Min.	.001	LPM	.000017	LPM
28317	CC/Hr.	1,699,011	CC/Hr.	.06	LPH	.001	LPH
.1247	Gal./Min.	7.481	Gal./Min.	.00026	Gal./Min.	.000004	Gal./Min.
7.481	Gal./Hr.	448.831	Gal./Hr.	.0159	Gal./Hr.	.00026	Gal./Hr.
1 LPM		1 LPH		1 Gal./Min.		1 Gal./Hr.	
60.	LPH	.0166	LPM	60	Gal./Hr.	.0167	Gal./Min.
.035	Cu. Ft./Min.	.00059	Cu. Ft./Min.	.1337	Cu. Ft./Min.	.002	Cu. Ft./Min.
2.1189	Cu. Ft./Hr.	.035	Cu. Ft./Hr.	8.021	Cu. Ft./Hr.	.1337	Cu. Ft./Hr.
1000	CC/Min.	16.667	CC/Min.	3.785	LPM	.063	LPM
60,002	CC/Hr.	1000	CC/Hr.	227.118	LPH	3.785	LPH
.264	Gal./Min.	.004	Gal./Min.	3,785.412	CC/Min.	63.069	CC/Min.
15.851	Gal./Hr.	.264	Gal./Hr.	227.125	CC/Hr.	3785	CC/Hr.

Pressure Unit Conversion Constants

(Most Commonly Used — Per International Conventions)

SenSym

	PSI ⁽¹⁾	in. H ₂ O ⁽²⁾	in. Hg ⁽³⁾	K Pascal	mili Bar	cm H ₂ O ⁽⁴⁾	mm Hg ⁽⁵⁾
PSI ⁽¹⁾	1.000	27.680	2.036	6.8947	68.947	70.308	51.715
in. H ₂ O ⁽²⁾	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
in. Hg ⁽³⁾	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
K Pascal	0.14504	4.0147	0.2953	1.000	10.000	10.1973	7.5006
mili Bar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H ₂ O ⁽⁴⁾	1.4223×10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mm Hg ⁽⁵⁾	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

NOTES:

1. PSI — pounds per square inch
2. at 39°F
3. at 32°F
4. at 4°C
5. at 0°C

Airspeed	
Knots	Inches of Mercury
60	0.1727
80	0.3075
100	0.4814
110	0.5832
120	0.6950
130	0.8168
140	0.9488
150	1.0910
175	1.4918
200	1.9589
225	2.4943
250	3.1002
275	3.7792
300	4.5343
325	5.3687
350	6.2859
375	7.2900
400	8.3850
425	9.5758
450	10.8675
475	12.2654
500	13.7756
525	15.4045
550	17.1590
575	19.0465
600	21.0749
650	25.5893
700	30.7642
750	36.5662
800	42.9378
850	49.8423
900	57.2554
1,000	73.5454

ALTITUDE (Feet)	EQUIVALENT PRESSURE (inches of Mercury)
-1,000	31.0185
-900	30.9073
0	29.9213
500	29.3846
1,000	28.8557
1,500	28.3345
2,000	27.8210
3,000	26.8167
4,000	25.8418
6,000	23.9782
8,000	22.2250
10,000	20.5770
12,000	19.0294
14,000	17.5774
16,000	16.2164
18,000	14.9421
20,000	13.7501
22,000	12.6363
25,000	11.1035
30,000	8.88544
35,000	7.04062
40,000	5.53802
45,000	4.35488
49,900	3.44112 (EST)
50,000	3.42466

TABLE I